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TECHNICAL REPORT BRL-TR-2829

IBHVG2 -- A USER'S GUIDE

RONALD D. ANDERSON
KURT D. FICKIE

JULY 1987

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Errata Sheet for BRL-TR-2829, "IBHVG2 -- A USER'S GUIDE"

Page	Description
41	After equation (A.14), reference to 'Figure 6' should be 'Figure 7'
43	Section C, first paragrah, last sentence: "...tube-based frame of reference (Figure 6), where $z_p \equiv x_p + x_r$, is as follows."
49	Equation (D.18) should be: $$A_w = \left[\frac{V_c}{A_b}\right]\pi D_b + 2A_b + \pi D_b\left[z_p - z_p(0)\right]$$ Equation (D.21) should be: $$\bar{v} = \frac{\dot{z}_p}{2}$$
50	Section E, third paragraph, second sentence: "These codes solve for surface area and unburned volume for the different grain types..."
55	Subscript definitions, last line should have " 0 " (zero) instead of " ϕ " (phi)
58	Graph at bottom of page should have following axis labels: Horizontal axis "Depth Burned (in)" Vertical axis "Surface Area (in^2)"
61	Appendix D, first paragraph, end of third sentence: "...integration step size (DELT in the $INFO deck)."
62	Appendix E, third paragraph, second sentence: "...case 5 took more time to compute on the Cray and the PC than..."
73	Test Case 2, second paragraph, end of fourth sentence: "...$TRAJ, and $INFO decks, and the graph at the end of Appendix B.)"

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IBHVG2, which stands for "Interior Ballistics of High Velocity Guns, version 2," is a lumped-parameter, interior ballistic computer code. The code, which was developed at the BRL, is an updated version of the classic Baer-Frankle interior ballistic code. IBHVG2 is used for calculation of interior ballistic trajectories, including gas pressure, projectile displacement and projectile velocity as a function of time. The code treats both regular and deterred propellants. It contains powerful variational and searching capabilties, so that it can, for example, search and find the "best" propellant dimensions, given the maximum allowable gas pressure.

This report thoroughly documents IBHVG2, so that all of its many features can be used effectively. The report contains a detailed description of the range of possible user input and a description of both the algorithms embodied along with the FORTRAN subroutines which implement them. There are also complete examples of input and output from the code. Although the code has been written to be as generally applicable as possible, the report has a short section describing modifications that are necessary to enable the code to run on various computers and compiler combinations. A machine-readable copy of the code can be obtained by contacting the authors of this report.

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CONTENTS

I. INTRODUCTION

The efficient design of large caliber guns and their corresponding charges requires an accurate simulation of the interior ballistic cycle. Simple lumped-parameter models are usually sufficient to predict the gross ballistic variables such as chamber pressure and projectile velocity to precision rivaling experimental capabilities. This accomplishment allows ballisticians to focus on experiments which either validate the models or are used to extend the modeling effort. Since computer simulation is very inexpensive in relation to experimental testing, once it has been established that the model corresponds to actual firings, the designer can try out many different ideas under a variety of circumstances. The net result is a superior round at minimum cost.

This report describes one such code which is widely used in the interior ballistics community. IBHVG2, which stands for "Interior Ballistics of High Velocity Guns, version 2", was developed by describing the ballistic events as a set of ordinary differential equations which are solved by marching forward in time. One feature which has helped to popularize the code is its flexible method of inputting user options, allowing the designer to focus his energies on the ballistics instead of the computer programming aspects. Past experience suggests that IBHVG2 is general enough to investigate most gun/charge scenarios without any modifications to the computer algorithms.

Most useful computer codes are the product of evolution and IBHVG2 is no exception. The basic principles are described in the well-known Baer-Frankle report[1]. IBHVG1, which was written by Robert Deas of BRL, is essentially the Baer-Frankle methodology written in FORTRAN with an improved user-interface. Some ideas were also borrowed from MPRGUN written by Paul Baer, also of BRL. In 1981, mission requirements dictated that a new code be written which would properly model deterred propellants and provide a better description of heat transfer to the gun tube. Franz Lynn was the sole author of the coding efforts, although numerous discussions among the scientists in the Interior Ballistic Division of BRL helped shape the final form and goals. Development ceased after his untimely death in 1983.

The basic operation of the code is quite simple. From a sufficient description of the gun system and its propelling charge, IBHVG2 can simulate the burning of the primer and propellant while computing the time trace of a variety of variables to include: mean gas pressure and temperature of the gun chamber, acceleration and velocity of the projectile, and the mass fraction of each unburned propellant. One of the advanced features of the code is the ability to automatically vary its inputs for a new simulation in an iterative fashion. This is very useful for charge design work. As an illustration, the ballistician could fix the maximum allowable gun tube pressure and require the code to vary some characteristic of a specific propellant (say, the grain web size) until the goal is attained. Such iterations can, in turn, be nested. Extending our example, one may desire to meet the target pressure while optimizing on the exit velocity of the projectile by varying another propellant characteristic. Detailed examples are included in Appendix E to serve as a guide to the reader and to demonstrate the versatility of the code.

Figures 1 and 2 are included to demonstrate the correspondence between range firing data and IBHVG2 simulations. The data come from a series of experiments investigating short, slotted sticks (25-mm) fired in a 155-mm howitzer (see reference [2]). They are representative of results one would expect for granular charges in a large caliber weapon. The input for computer simulation is based on propellant data obtained from closed-bomb experiments and

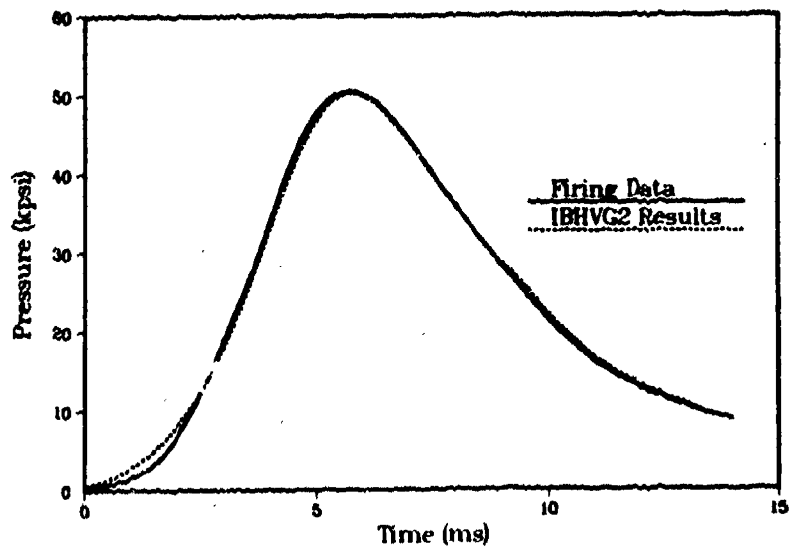


Figure 1. Comparison of Pressure Histories

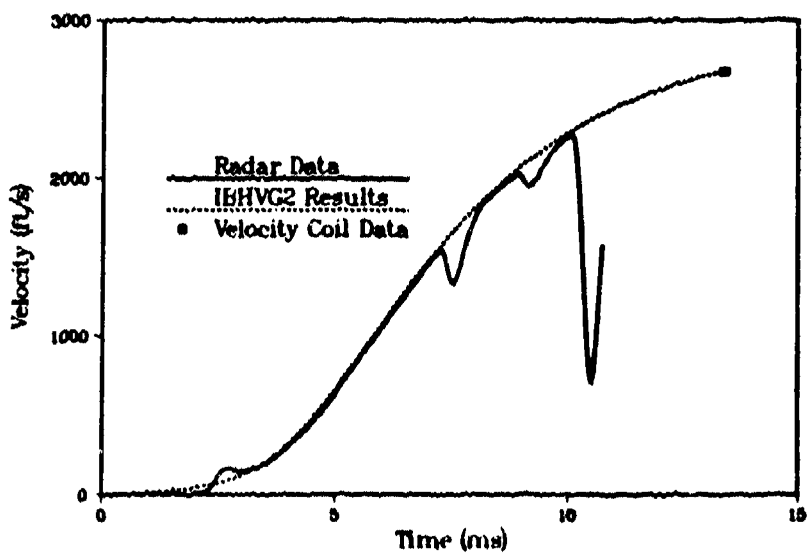


Figure 2. Comparison of Velocity Histories

the projectile resistance profile corresponds to previously recorded measurements for a M101 projectile. That is to say, there was no curve fitting since there are no free parameters; all input data either involved direct physical measurements or were obtained by independent experiments.

As one can see, the comparison of range data with an IBHVG2 simulation is reasonably good. Both the pressure and velocity histories appear to be within the experimental error of the measurements. This point is worth some elaboration. In these firings there are two sets of measurement records to estimate variance. One consists of time traces from redundant transducers of the same event such as two pressure gages at the same axial distance of the gun tube. The other involves measurements from repeated, but equivalent, firings. Both sets are useful for different reasons. The former gives quantitative information about transducer and measurement error, while the latter provides insight about reproducibility of the experiment.

One should note that the time origin for the firing data is arbitrary; therefore, to aid in the comparison, the origin of the data is adjusted such that the maximum pressure occurs at the same time as the simulation. Using this technique, the pressure simulation falls within the experimental uncertainty of the range data (pooled standard deviation of about 0.4 kpsi) with the exception of the first 2.5 ms. This region is of interest because it describes the portion of the interior ballistic event least understood.

There is a strong temptation to explain the disparity to the fact that IBHVG2 simulates the propellant burning uniformly, whereas, experiments have demonstrated that flamespreading is neither complete nor instantaneous immediately after ignition. Presumably, this would cause the pressure to initially lag behind the computed result. Examination of various transducer channels suggest another factor to be considered. It is common to observe two separate channels with results in excellent agreement everywhere except the first millisecond or so. This behavior could be attributed to slight variations in the individual pressure ports (sometimes described as "plugging") or it could be a manifestation of the finite dynamic response of the transducers. Pressure transducers for the study of ballistics are calibrated and chosen based on accuracy from static tests and linearity over the range; frequency response is of secondary importance. In summary, it is not clear which plays the most significant role, but it is obvious that this region contains the most uncertainty. The key point is that for early times IBHVG2 pressures tend to exceed those recorded on the firing range.

The velocity comparison shows two independent measurements from the range. The solid curve is obtained from Doppler radar where the time origin is the same as obtained for the pressure comparison described above. The oscillation exhibited prior to projectile exit is an artifact of the technique. The signal appears to have been severely attenuated, probably because this round had some blow-by gases which were absorbing the radiation. The bump at 2.5 ms should also be disregarded. This is typical of Doppler measurements due to the difficulty of discerning a velocity of a slow moving object. The star marks the velocity recorded independently via velocity coils near the gun muzzle. The time coordinate is arbitrary, but the velocity value is precise to within 0.2 percent (based on the pooled variance of 12 shots). The IBHVG2 estimate for muzzle velocity falls inside this bound.

While writing this report, we expected just to include a comparison from any former experiment. To our surprise, it appears that experimental curves are seldom compared to IBHVG2 simulations, although virtually all gun firings are preceeded by some lumped-parameter calculation. Most investigations just compare the maximum pressure and the muzzle velocity. In the hands of an experienced ballistician this may be sufficient. However, the primary reason for not comparing the curves is due to the difficulty of getting the range data and the

simulation results in a suitable format and on the same computer. It is the sincere hope of the authors that this will no longer be an obstacle. The code is now sufficiently portable to be run on most any computer with a FORTRAN compiler. As demonstrated in Appendix E, a single simulation can be executed on a microcomputer on the order of a minute. Therefore, it would be reasonable to run the code on the same computer which does the data acquisition. Then a comparison can be established immediately after the firing. It is clear that the best time to reconcile or verify a discrepancy is soon after the experiment when all the details are fresh.

Such an arrangement could have advantages beyond convenience. If the curves match as well as the one shown in this report over a wide range of ammunition, the simulation could almost be used as a quality control mechanism. Any significant deviations would signal a serious problem with either the experiment or what the user perceives as correct input. If, on the other hand, the curves do not match as well with some rounds as others, then we will have identified some new research issues. Documenting problem cases would, at the very minimum, aid future simulation efforts. Regardless, we predict a synergistic effect if some modeling is shifted to those who actually do the firing.

This report is designed to be both an introduction and a user's guide to IBHVG2. The first section is a complete reference manual for the construction of the user input decks. It is followed by a short description of each FORTRAN subroutine found in the code. The third section describes the ordinary differential equations and the constitutive relations used to create the code. Both the physics and the mathematical assumptions are briefly discussed. The remainder of the report describes issues about executing the code to include some examples.

This documentation is essentially an attempt to pull together much of the information known about the IBHVG2 code and put it in one place for the convenience of the user. The fact that both authors are novices at using the code probably served as an advantage. More times than we care to recount, one of us had to seek out an advanced user to understand something about the folklore or discover some fact which was "common knowledge" in using the code. Undoubtedly, in the process we have absorbed some information which now makes sense to us, but is not clearly stated in this report. Familiarity has a tendency to obscure subtle understandings. When the reader uncovers such failures, we would appreciate hearing from you so it can be corrected for a future guide. Comments about useful additions or omissions are also encouraged.

II. DESCRIPTION OF INPUT DECKS

A. Syntax Rules

Input data stream for IBHVG2 consists of a serie "decks." The start of each deck is demarcated by a line starting with a "$" in the first co umn and followed by a four letter mnemonic. All lines of input data between decks should in principle be closely related ballistic parameters.

Inputs are free format in that more than one can be included per line. Comments may be incorporated by preceding them with a "$" in any column other than the first. The formats are

$$variable = value$$

for ordinary unsubscripted variables and

$$variable\ (sub) = value_1, \cdots, value_n$$

for subscripted variables, with commas and/or blanks between consecutive variable/value constructs. Integer and real formats are legal for all numerical values. Character strings must be delimited with either apostrophes or quotes. All keywords, to include deck cards and variable names, must be in uppe ase.

The first blank between consecutive variable/value fields is the legal delimiter; any additional ones are ignored. Blanks embedded in variable names, subscripts, or numeric values are significant but illegal. Leading blanks in character strings are squeezed out.

An omitted "(sub)" in a subscripted variable is taken to be 1. Consecutive values fill locations sub, sub+1, sub+2, etc., while pairs of commas with nothing or blanks between them advance to the next subscript (i.e., a subscript is skipped over). All character variables default to blank strings while numerical variables default to either zero or a convenient value listed below. If a variable is multiply-defined, the last input overrides all previous ones. All syntax errors are flagged. A list of all valid deck names follows as well as descriptions of all variables within each deck.

B. Decks

$COMM

All cards between a $COMM and the next deck card are ignored to allow the tagging of a data input file with user comments.

$END

This control card signifies end-of-input for the current case. IBHVG2 will then execute. Afterwards, it will start reading the next card, if any. This is to allow the processing of other runs or for the code itself to generate runs internally. An end-of-input condition for a user's input deck is processed as if the $END card was read in. *A frequent mistake by novice users is to include the $END and follow it by a blank line.* The code assumes this is another run and proceeds to produce errors due to insufficient information.

$FIND

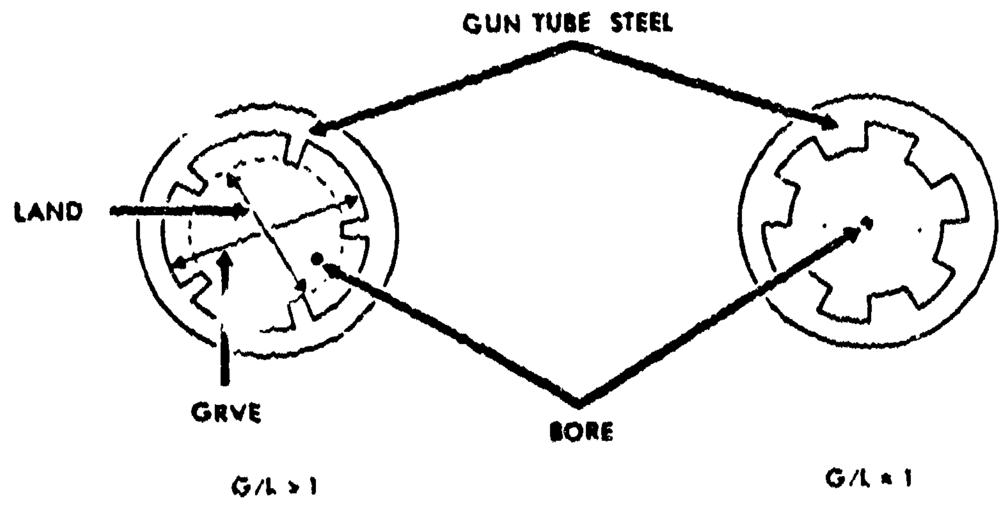
For inputs to a general variation-and-search utilizing function minimization techniques (see reference [6] for algorithm). Up to six $FIND decks may be submitted in one run allowing a variation in six dimensions. A list of additional option variables for outputting is found at the end of this section.

VARY	name of parameter including any subscript
DECK	name of deck containing parameter; 4 characters max; may not be PARA, PDIS, FIND, PMAX, or TDIS
NTH	number of deck if there are several with same name [default = 1]
FROM	initial value of parameter in proper units
EPS	error tolerance
OUTV	name of desired output variable from run completion variables (see end of this section)
CODE	0 to achieve desired value of OUTV variable 1 to maximize OUTV variable
VAL	desired value if CODE is 0, else ignored
MULT	multiplier for function-minimizer residual [default = 1.0]
MIN	min allowable value of VARY parameter [default = 0.0]
MAX	max allowable value of VARY parameter [default = 1.0E+10]

$GUN

For variables related to gun-tube geometry, namely:

NAME TYPE	name of gun; 28 characters max
CHAM CV CVOL	chamber volume [in^3]
GRVE	groove diameter [*in*]
LAND	land diameter [*in*]
TRAV LENG	travel to shot-exit [*in*]
G/L	ratio of groove to land surface area; smooth-bore if G/L=0 [default]
TWST	rifling twist [*calibers/turn*]
LOPT	0 [default] to ignore LDEN 1 to calculate CHAM from total charge weight and LDEN 2 to calculate total charge weight from CHAM and LDEN; primer & charge weights must [illegible] specified; they are scaled proportionally to sum to required total charge weight
LDEN	ratio total charge [illegible]t/chamb[illegible]r volume [g/cm^3]; used when LOPT = 1 or 2 [defa[illegible] = 0.2] *CAUTION: LDEN ca[illegible] datio[illegible] re done after C/M (which may have altered charge w[illegible] [illegible] used.*
CLEN	effective chamber le[illegible] [illegible]in] for scaling in-chamber pressure gage locations [defa[illegible] [illegible]V/bore area]
NGAG	number of gage locations [default = 0 [illegible]x = 30]
GLOC	gauge location array of size NGAG [*in*] [defaults = 0.0]. Distance is measured (+) downtube from the breech or (-) into chamber from the initial position of the projectile base. *CAUTION: IBHVG2 will discard duplicate or out-of-range values and will rearrange distances in ascending order, if necessary. This should be kept in mind when using, for example, a $SAVE deck--the position you reference may not be the one the computer code decided upon.*



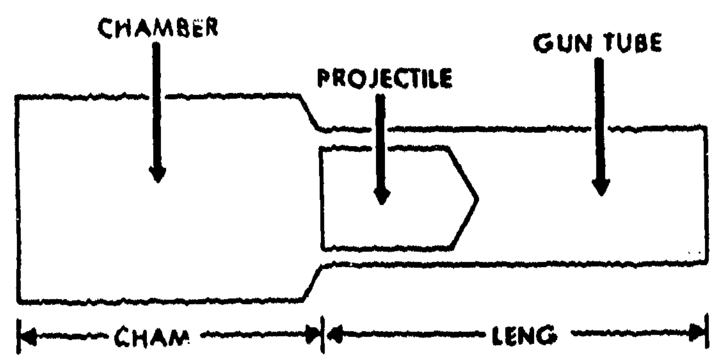


Figure 3 Gun Parameters

$HEAT

For heat-loss-related variables, namely:

TSHL	tube shell thickness for heat sink [*in*] [default = 0.004]
CSHL	shell specific heat [$in-lb_f/lb_m-K$] covering a broad range of steels [default = 1848.0]
RSHL	shell material density [lb_m/in^3] [default = 0.284]
TWAL	initial wall tempera e [*K*] [default = 293.0]
H0	free convective heat transfer coefficient for air in the tube [$in-lb_f/in^2-sec-K$] [default = 0.0648]
HL	0 to ignore heat losses in energy balance 1 [default] to include heat losses

$INFO

For run-related inputs. The variables are:

DELT	max integration time step [*sec*] [default = 0.0001]
DLPU	1 [default] for DELP in units of time [*sec*] 2 for DELP in units of projectile travel [*in*]
DELP	integrator logout & print step [*sec*] or [*in*]; reset to DELT if DLPU = 1 and DELP < DELT
SOPT	0 to suppress file storage of run output [default] 1 to write trajectory data for each run into output file STORE for post-processing 2 to write only single-line summaries for each parametric run into file STORE; ignored if non-parametric runs are being conducted
GRAD	1 for Lagrange gradient [default] 2 for Pidduck-Kent gradient
UNIT	unit system for output; not implemented yet, but will be a choice between 0 for SI and 1 for English

POPT	print option array of size 6 [all defaults = 1]. Detailed descriptions given below between the double bars:
POPT(1)	0 to suppress 1 to print input echo
POPT(2)	0 to suppress trajectory print 1 to print default trajectory variables 2 to print user-specified $TDIS variables
POPT(3)	0 to suppress 1 to print IB summary
POPT(4)	0 to suppress blowdown calculation 1 to print blowdown phase (see reference [5], chapter 9) to include tube recoil when the recoil option is in effect (see $RECO)
POPT(5)	0 to honor above print options for every run of parametric variation 1 to honor above print options for first run of parametric variation and print a single-line summary thereafter 2 like 1, but summary print variables supplied via $PDIS specifications
POPT(6)	is currently unused
RUN TITL	run title on output pages; 48 characters max
EPS	max error for integrator time-step adjustment and transition tolerances [default = 0.002]
CONP	0 for usual non-constant-pressure run [default] 1 for run with constant pressure maintained by varying the burning rate of the single charge 2 for run with constant pressure maintained by varying the surface area of the single charge
PRES	desired constant breech pressure [*psi*] when CONP option is 1 or 2
TOL	error tolerance [*psi*] for PRES [default = 1.0]

$PARA

For parametric variations; up to four $PARA decks per run permit a four dimensional matrix to be systematically tried. The DECK must contain a nominal value of the variable to be VARY'd.

VARY	name of parametric variable including any subscript
DECK	name of deck containing variable; 4 chars max; may not be PARA, PDIS, FIND, PMAX, or TDIS
NTH	deck number if there is more than one [default = 1]
FROM	initial value of variable
TO	final value of variable
BY	increment/decrement value

$PDIS

Each deck defines one variable to be printed in lieu of the default set for each line of the parametric summary print. There can be up to 11 $PDIS decks in effect: one for each variable printed for the interior ballistic cycle. Be sure to include the line POPT(5)=2 (print option) in the $INFO deck. To write the summary information to a file attached to UNIT=7, include the line SOPT=2 in the $INFO deck. ($PDIS is similar to the $TDIS deck). A list of additional option variables for outputting is found at the end of this section.

SHOW	name of variable to print; 4 chars max
DECK	name of deck containing the desired variable; any deck may be named except PARA, PDIS, FIND, and PMAX
NTH	number of deck if more than one [default = 1]
MULT	number to multiply data value by [default = 1.0]
DIV	number to divide data value by [default = 1.0]
REM1 REMK	20 character remark string for titles and file STORE

$PMAX

For variation of charge weight or web to achieve a desired maximum breech pressure. If web is varied, grain ratios rather than grain dimensions may be the better choices in the $PROP deck concerned. The $PROP deck must contain a nominal value of charge weight and web, even though one or the other will be varied in the $PMAX operation. Note that a DECK='PROP' card is not needed in a $PMAX; the program knows that it must be varying some propellant characteristic. If you include DECK='PROP', the program will complain but will still do the proper things.

VARY	variable name in a $PROP deck including any subscript
NTH	number of $PROP deck [default = 1]
TRY1	first value of VARY to try
TRY2	second value of VARY to try; third and subsequent guesses are based on interpolation. NOTE: the last two guesses from the previous run are employed as the first two guesses in second and subsequent $PARA runs
PMAX	maximum breech pressure [*psi*] sought
EPS	error tolerance [*psi*] for PMAX; [default = 1.0].
LOOP	max number of tries before quitting [default = 20]
MIN	mininmum allowable value of VARY parameter [default = 0.0]
MAX	maximum allowable value of VARY parameter [default = 1.0E+10]
NPMX	0 [default] if PMAX refers to the max breech pressure ever achieved during the run *n* where $n \in (1,2,...,5)$ if PMAX refers to the NPMX-th local breech pressure maximum achieved

$PRIM

For primer data. The "primer" is considered completely burned at the start of integration. For this reason, it is considered wise to include only enough primer to reach sufficient pressurization to ignite the propelling charge. Real primers are usually modelled with IBHVG2 by simulating the function with both a $PRIM and a $PROP deck. A typical correspondence is 10% by weight for the $PRIM and 90% as a $PROP. Constant-pressure runs may include or exclude a primer. A primer is mandatory for conventional simulations.

NAME TYPE	name of primer; 28 characters max
GAMA	specific heat ratio
FORC	force $[ft-lb_f/lb_m]$
COV	covolume $[in^3/lb_m]$
TEMP	flame temperature $[K]$
CHWT WT CHGW C CW	weight $[lb_m]$

$PROJ

For projectile-related variables.

NAME TYPE	projectile designation; 28 characters max
PRWT WT	projectile weight [lb_m]
COPT	0 [default] to ignore C/M 1 to calculate PRWT from total charge weight & C/M 2 to calculate total charge weight from PRWT & C/M; primer and all charge weights must be specified, but they will be scaled proportionally to sum to the required total charge weight
C/M	used when COPT=1 or 2; ratio of total charge weight and projectile weight [default = 1.0]
SOPT	0 [default] bypass PRWT calculation based on subprojectile parameters and sabot formula 1 find PRWT based on projectile weight estimation formula of Burns (see Reference [3]) 2 find PRWT based on same weight estimation formula using coefficients yielding 15% lighter sabot
WTSP	subprojectile weight [lb_m]
LSP	subprojectile length [*in*]
DSP	subprojectile diameter [*in*]
PDES	max design pressure [*psi*] for saboted projectile
SABO	sabot weight [lb_m]; *not input—set by IBHVG2*

$PROP

Defines a main propelling charge element. IBHVG2 will recognize up to five such decks and considers them independently (i.e., order is unimportant). The following are basic input variables most useful for describing homogeneous, undeterred grains:

NAME TYPE	name of propellant; 28 chars max
RHO DENS	density [lb_m/in^3]
GAMA	specific heat ratio
FORC	force [$ft-lb_f/lb_m$]
COV	covolume [in^3/lb_m]
TEMP	flame temperature [K]
CHWT WT CHGW C CW	weight [lb_m]
	burning rate $=\beta P^\alpha$ [in/s] where P is mean pressure [psi]
ALPH	burning rate exponent, α
BETA	burning rate coefficient, β
EROS	erosive burning coefficient, empirical factor multiplied by projectile velocity [in/s] to add to burning rate [default = 0.0]
GRAN FORM	granulation code chosen from 7PF (or 7P), 1PF (1P), CORD, RECT (SLAB), SPHR (BALL), SLOT, 37HX (37H), 19HX (19H), 19PF (19P), GEN, PIE (STAR), GHEX (HEX), MONO (see Appendix B)

WI WIN	inner web for cylindrical/hexagonal grains [*in*]
WO WOUT	outer web for cylindrical/hexagonal grains [*in*]
WM WMID	middle web for cylindrical/hexagonal grains [*in*]
WEB WB	common value of all inner, middle, and outer webs [*in*]; also resets WI/O
D DIAM GDIA	grain diameter, if applicable [*in*]
PD DP PDIA	perf diameter, if applicable [*in*] [default = 0]
SLOT	slot width in SLOT and PIE grains [*in*]
NSLT	number of diametral slots in PIE grain ≥ 2
NRNG	number of concentric rings of perfs around central perf in HEX grains; ≥ 0 [default = 2]
L GL LEN GLEN	grain length, if applicable [*in*]
WDTH	grain width in RECT grains [*in*]
THCK	grain thickness in RECT grains [*in*]
NSUR	number of depth/surface pairs for GEN grain [default = 1, max = 10]
DEPB	depths-burned array [*in*] for GEN grains; ignored if NSUR = 1
SURF	surface area array [in^2] for GEN grains
IGNC	code specifying charge ignition: 0 to ignite at start of integration [default] 1 to ignite at some time [*s*] 2 to ignite at some projectile travel [*in*] 3 to ignite at some mean pressure [*psi*] 4 to ignite at some Z (mass fraction burned) of the charge described by the previous $PROP deck

THRC	threshold value for ignition if IGNC > 0
IGNS	array of size 3 specifying ignition codes for the perf, end, and lateral grain surfaces, respectively; same codes as IGNC; ignored if IGNC > 0.0
THRS	array of threshold values for surface ignition
PA-B	0 [default] for standard treatment of charge; set automatically if grain has no perfs or if run has either constant-pressure option set 1 for perf-augmented burning of charge until grain fracture
DSCF	Robbins-Horst discharge coefficient in weight flux computation for perf-augmented burning model [default = 1.0] (see Reference [4])
FRAC	0 [default] for no user-defined grain fracture criterion of charge with PA-B = 1. *NOTE: web burn-through turns off perf-augmented burning.* 1 to specify pressure-difference grain fracture threshold for charge with PA-B = 1. *NOTE: web burn-through triggers fracture.*
NFRG	number of fragments when 1PF grain fractures ≥ 1
THRF	absolute value of difference between chamber and perf pressures for grain fracture [*psi*]; ignored if FRAC = 0 [default = 0.0]

IBHVG2 will calculate grain dimensions if given either actual measurements, or alternatively, a single measurement combined with ratio specifications. This latter technique is quite useful when the code is used to optimize a charge design. For example, a CORD grain can be defined by D and L, or by L and the ratio L/D. For a 7-perforated grain, WI and DP together with WI/O, D/DP, and L/D will completely specify the grain geometry. The slot width of a SLOT or PIE grain will be calculated given SW/D and D. Care must be taken to avoid over-specified or inconsistent information since the computer program may make arbitrary or poor decisions. IBHVG2 prints the grain dimensions prior to ballistic calculations; experienced users of the code always scrutinize this portion of the output for any surprises.

L/D	grain length/grain diameter
L/DP L/PD	grain length/perf diameter
D/DP D/PD	grain diameter/perf diameter

L/WD	grain length/grain width
WD/T	grain width/grain thickness
SW/D	slot width/grain diameter
WI/O	inner web/outer web for multiperforated grains; web eccentricity for single perf grains [default = 1.0]

For deterred grains, further (or replacement) inputs to handle variable thermochemistry and burning rates are necessary. Visualize each grain having, in general, three disjoint surfaces:

Surface	*Description*
P	perf (includes the slot, if any)
E	end
L	lateral

Extending inward from each surface are layers 1, 2, 3, and 4 (the innermost or "core"), and any or all of the first three may be of zero thickness (nonexistent) on one or more of the P, E, or L surfaces. The core layer is always present and its properties, unlike those of the outer layers, are independent of depth. As there is only one common 4th layer, L-specifications for the core override all others to prevent conflicts. All depth-varying properties are consecutively defined at the outer surface of each layer from the outside in so each of the following is an array of size 4. Linear interpolation is performed by IBHVG2 when intermediate values are required.

RHOP	density $[lb_m/in^3]$	on P surfaces
RHOE		on E surfaces
RHOL		on L surfaces
GAMP	specific heat ratio	on P surfaces
GAME		on E surfaces
GAML		on L surfaces
FRCP	force $[ft-lb_f/lb_m]$	on P surfaces
FRCE		on E surfaces
FRCL		on L surfaces
COVP	covolume $[in^3/lb_m]$	on P surfaces
COVE		on E surfaces
COVL		on L surfaces
TMPP	flame temperature $[K]$	on P surfaces
TMPE		on E surfaces
TMPL		on L surfaces

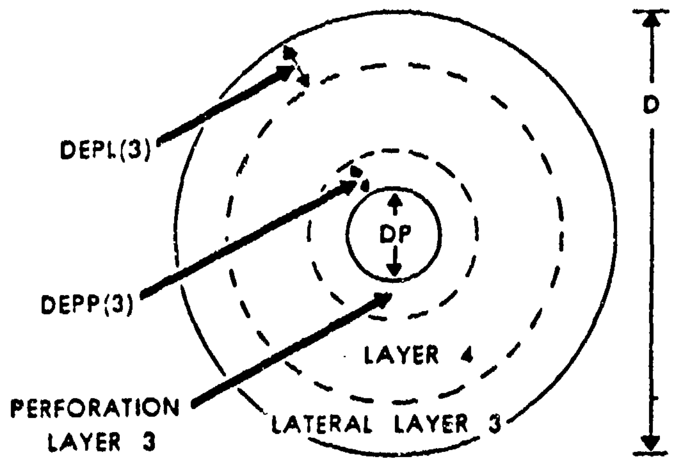


Figure 4. Two-Layer, Single-Perf Grain (end-view)

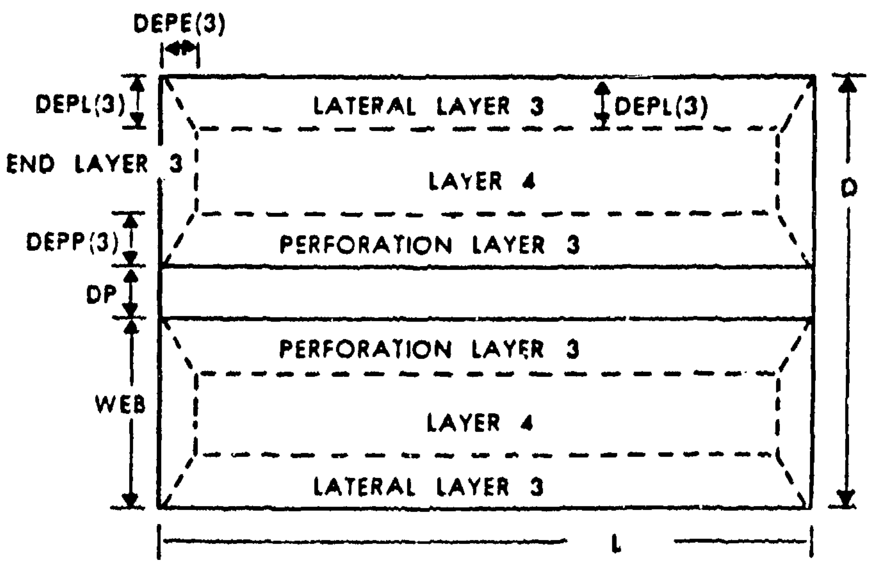


Figure 5. Two-Layer, Single-Perf Grain (lateral-view)

Arrays of size 3 specify the transition depths [*in*] between the first and second, the second and third, and the third and fourth layers, respectively, for each surface.

DEPP DEPE DEPL	transition depths [defaults = 0.0]	on P surfaces on E surfaces on L surfaces

Transition depths will be calculated by IBHVG2 if positive ratios specifying transition depths as fractions of surface-to-surface distance are input. Arrays of size 3 store the ratios [the default for all values is 0.0].

DP/S	ratios of transition depths on P surfaces to WI; used for perforated grains only
DE/S	ratios of transition depths on E surfaces to: • min(GL,WDTH) for RECT • GL for perforated & CORD grains
DL/S	ratios of transition depths on L surfaces to: • D for CORD & SPHR grains • THCK for RECT grains • WI for perforated grains
FP/L	ratios of DP/S to DL/S; DP/S values will be found given FP/L and DL/S; useful for defining a relation between transition depths on P and L surfaces

Finally, burning rate data for the outer surface of each layer may be incorporated via several alternative methods. It should be noted that interpolation is linear for depths and betas, but logarithmic for alphas and tables of pressure versus burning rates.

NTBL	method of specifying burning rate inputs ... absolute value is number of table entries on every surface layer; range of values: -10 to +10 < 0 to specify betas and alphas as tabular functions of mean pressure [*psi*], NTBL triples in all = 0 to define one beta/alpha pair [default] > 0 to specify burning rates [*in/sec*] as tabular functions of mean pressure [*psi*], NTBL pairs in all. *NOTE: if NTBL = 1, burning rate is constant so corresponding pressure value, if any, is ignored.*
PR1L	pressures [*psi*] on outside of layer 1, L surface. PR2L, PR3L, PR4L, PR1E, PR2E, PR3E, PR4E, PR1P, PR2P, PR3P, PR4P are defined similarly.

BR1L	burning rates [*in /sec*] on outside of layer 1, L surface. BR2L, BR3L, BR4L, BR1E, BR2E, BR3E, BR4E, BR1P, BR2P, BR3P, BR4P are defined similarly.
CF1L	burning rate coefficients (betas) on outside of layer 1, L surface. CF2L, CF3L, CF4L, CF1P, CF2P, CF3P, CF4P are defined similarly.
EX1L	burning rate exponents (alphas) on outside of layer 1, L surface. EX2L, EX3L, EX4L, EX1E, EX2E, EX3E, EX4E, EX1P, EX2P, EX3P, EX4P are defined similarly

$RECO

For recoil data. In the model currently available, the gun tube freely recoils under the influence of breech pressure less resistance pressure. In IBHVG2 Version 400, this option has not been fully tested and should not be considered reliable.

RECO	0 for fixed tube, no recoil [default] 1 to employ recoil option
RCWT WT	weight [*lb*] of tube and recoiling parts
NAME TYPE	name of recoil system; 28 characters max

$RESI

This precedes resistance pressure inputs. The variables are:

NPTS	number of travel/pressure pairs [min = 0, max = 20]
TRAV	projectile travel array of size 20 [*in*]
PRES	resistance pressure array of size 20 [*psi*]
AIR	0 to suppress adding in air resistance 1 to include air resistance [default]
HTFR	fraction of work done to overcome barrel resistance which is used to pre-heat tube wall; $0.0 \leq \text{HTFR} \leq 1.0$ [default = 0.0]

$SAVE

Actually, not a deck card, but a control card. If it is the first card in a run after an $END card, the values of all input variables are retained, so that succeeding decks need only update selected variables. If an $END card is not followed by a $SAVE card, all input variables must be reinitialized. See test cases 3, 4, and 5 in Appendix B for examples.

$TDIS

Each deck defines one variable to be printed in lieu of the default set for each line of the trajectory print. There can be up to 11 $TDIS decks in effect: one for each variable printed for the interior ballistic cycle. Be sure to include the line POPT(2)=2 (print option) in the $INFO deck. To write the trajectory information to a file attached to UNIT=7, include the line SOPT=2 in the $INFO deck. ($TDIS is similar to the $PDIS deck). The list of option variables available for use is found at the end of this section.

SHOW	name of variable to print from deck TRAJ; 4 characters max
MULT	number to multiply data value by [default = 1.0]
DIV	number to divide data value by [default = 1.0]
REM1 REMK	20 character remark string for titles and file STORE

Trajectory Variables

Below is a list of keyword variables which can be used in conjuction with the $TDIS, $FIND, and $PDIS decks to reference quantities other than the default set. To use them with $PDIS and $FIND, one must include the line DECK='TRAJ'; a reference within $TDIS assumes the keyword will come from the following list. Test cases 3 demonstrates the use of $TDIS to change the trajectory display printed during the ballistic cycle.

MEAN	mean gas pressure in chamber [*psi*]
PRFP	array of size 5 of mean gas pressure in perfs [*psi*] of each charge; equal to MEAN if no perf-augmented burning in that charge at current time step
GAGE	array of size 30 of gage pressures [*psi*]
BRCH	breech pressure [*psi*]
BASE	pressure at projectile base [*psi*]
PDOT	d(mean chamber pressure)/dt [*kpsi* /*ms*]

PDTP	array of size 5 of d(mean perf pressure)/dt [$kpsi/ms$], one for each charge
TBAR	mean gas temperature in chamber [K]
PRFT	array of size 5 of mean gas temperature in perfs [K] of each charge; equal to TBAR if no perf-augmented burning in that charge at current time step
FRCR	bore-friction resistance pressure [psi]
AIRR	air resistance pressure [psi]
TOTR	sum of FRCR and AIRR
TWAL	temperature of tube wall shell [K]
WTB	array of size 5 of weight burned of each charge [lb_m]; reference by subscript
WTBR	array of size 5 of weight-burning rate of each charge [lb_m/sec]; reference by subscript
WTBT	total weight of gas in chamber [lb_m]
PRJE	projectile translational kinetic energy [$in-lb_f$]
PRJ%	PRJE * 100 / TOTE
PRPE	propellant and gas kinetic energy [$in-lb_f$]
PRP%	PRPE * 100 / TOTE
ROTE	projectile rotational kinetic energy [$in-lb_f$]
ROT%	ROTE * 100 / TOTE
FRTE	barrel-frictional work to tube [$in-lb_f$]
FRT%	FRCE * 100 / TOTE
FREE	barrel-frictional work not absorbed as heat to the tube wall [$in-lb_f$]
FRE%	FREE * 100 / TOTE
DRGE	work done against air in barrel [$in-lb_f$]
DRG%	DRGE * 100 / TOTE
RECE	kinetic energy of recoiling tube [$in-lb_f$]

REC%	RECE * 100 / TOTE
HETE	energy lost as heat convected to tube wall [$in-lb_f$]
HET%	HETE * 100 / TOTE
LOSE	sum of all energy losses [$in-lb_f$]
LOS%	LOSE * 100 / TOTE
TOTE	total chemical energy released by combustion [$in-lb_f$]
EDOT	d(TOTE)/dt [$in-lb_f/sec$]
GASE	internal energy of gas [$in-lb_f$], i.e., TOTE - LOSE
GAS%	GASE * 100 / TOTE
SRF	array of size 5 of burning-surface area of each charge [in^2]; reference by subscript
SRFT	total surface area of all ignited charges [in^2]
TIME	time [ms]
TRAV	projectile displacement from initial position [in]
VEL	ground-based projectile velocity [ft/sec]
ACCL	projectile acceleration [$G's$]
Z	array of size 5 of charge weight fractions burned; reference by subscript
DB-P	array of size 5 of depth burned into P surface of each charge [in]; reference by subscript
DB-E	same as above for E surfaces
DB-L	same as above for L surfaces
DB-F	save as above for F (fracture) surfaces
BR-P	array of size 5 of burning rate on P surface of each charge [in/sec]; reference by subscript
BR-E	same as above for E surfaces
BR-L	same as above for L surfaces
BR-F	same as above for F (fracture) surfaces

Run Completion Variables

These are output variables defined after a complete IBHVG2 run. Typically they represent some global extrema which can only be ascertained at the conclusion of ballistic computation. For example, a maximum pressure is determined after shot ejection, while there could be several local maxima during the pressure history. The variables may be referenced by name using $PDIS (with DECK='OUT') as in test case 6, or by $FIND as the value inserted for OUTV as shown in test case 5.

PMAX	max breech pressure [*psi*]
HUMP	array of size 5 of local breech pressure maxima [*psi*]
GMAX	array of size 30 of gauge pressure maxima [*psi*]
VMUZ	muzzle velocity [*ft/s*]
AMAX	max acceleration [*g's*]
BMAX	max base pressure [*psi*]
X@BO	array of size 5 of projectile position [*in*] at charge burnouts; reference by subscript
PMUZ	base pressure at shot exit [*psi*]
ZMUZ	array of size 5 of charge weight fractions burned at shot exit; reference by subscript
IMPL	final impulse (momentum) [$lb_f - s$]
LDEN	calculated loading density [g/cm^3]

III. SUBROUTINE DESCRIPTIONS

AUXGEN

check consistency of charge weight and densities specified for FRMGEN charge

AUXHEX

add to weight of core of nth grain the contributions from P, E, and L layers with linearly-varying density .. used for hexagonal or cylindrical grains with NPERFS(NTH) number of perfs

AUXMON

add to weight of core of nth grain the contributions from P, E, and L layers with linearly-varying density .. used for monolithic grains only

AUXSLT

add to weight of core of nth grain the contributions from P, E, and L layers with linearly-varying density .. used for slot grains only

AUXSTR

add to weight of core of nth grain the contributions from layers with linearly-varying density on IASUB-th surface .. used for rectangular grains only

BADBRN

determine if grain surfaces in 01p, slot, 07p, 19p, 19h, or 37h have burned beyond core of grain

BLDATA

define static parameters, including I/O device numbers, alphanumeric characters set, and version number of IBHVG2

BRNCMP

return a burning rate through BRNCMP

BRNRAT

lookup burning rates as function of pressure and interpolate linearly as function of depth burned

BULDEK

define input variables for projectile

CALPRJ

calculate projectile weight, if required, based on projectile weight estimation formula cited in ARBRL-TR-02364, p. 24, by Burns (See Reference [3])

COMDEK
read through comment deck

CPRCHK
error check input if constant pressure run

CPRDAT
store current values before and restore values after tentative integration step for constant pressure run

CRITIG
return value of ignition-criterion variable for nth charge based on ignition code for comparison with threshold value

CRKLIN
parse input line, crack and classify fields as numeric, string, or variable name, and flag syntax errors

CRKNUM
stash numeric value in field number, NFIELD, or flag error

CRKSUB
stash integer subscript in field number, NFIELD, or flag error

CRKTIT
stash start and stop columns of string in field number, NFIELD

CRKVAR
stash variable name and subscript, if any, in field number, NFIELD, or flag error

DATINP
initialize input variables and call appropriate input routines

DEFPAG
define number of lines/output page

DERIV1
calculate derivatives for ODE solver during IB cycle

DERIV2
calculate derivatives for ODE solver during evacuation phase (treatment drawn from Corner, Chapter 9 of Reference [5])

DFQSET
set up eqns for solver KUTMER

DODPDT
calculate d(mean pressure)/dt

DRIVER
drive IB solver in selected modes

ECHOIN
echo inputs

ECHOPR
echo propellant input data

ENEQST
calculate mean temperatures and pressures

EVPREP
initialization and setup for evacuation cycle

FILLCB
fill common blocks as input cards are interpreted

FINDEK
define input variables driving automatic program search for desired conditions

FNEVAL
compute residual as function value FBAR for FUNMIN

FORMFN
calculate instantaneous grain surface areas and fractions burned for the grains in each charge

FRM01P
find surface areas for 01-perf cylindrical grain geometry

FRM07P
find surface areas for 07-perf cylindrical grain geometry

FRM19H
find surface areas for 19-perf hexagonal grain geometry

FRM19P
find surface areas for 19-perf cylindrical grain geometry

FRM37H
find surface areas for 37-perf hexagonal grain geometry

FRMADJ
return trial value of surface area in constant pressure run

FRMCRD
find surface areas for cord grain geometry

FRMGEN
find surface area for charge with user-specified values of surface area as function of depth burned

FRMHEX
find surface areas for general hexagonal grain geometry

FRMMON
find surface areas for monolithic, perforated, clindrical grain geometry

FRMPIE
find surface areas for pie grain geometry

FRMSLT
find surface areas for slotted grain geometry

FRMSPH

find surface areas for spherical grain geometry

FRMSTR

find surface areas for strip (rectangular) grain geometry

FSTORE

store parameter values determined by FUNMIN

FUNMIN

finds the minimum of function of n variables based on method in BRL-TN-1677 by J.D. Wortman (See Reference [6])

GAGSET

find and sort gage positions

GENISL

finds the surface area-contributions due to inner slivers for a multiperforated propellant grain

GENOSL

finds the surface area-contributions due to outer slivers for a multiperforated propellant grain

GRADNT

calculate pressure at breech, projectile base, & gages

GUNDEK

define input variables for gun tube

HDRSTO

store descriptive information in file for post-run processing of detailed IB and evacutaion cycles

HELPPR

format and build output lines for ECHOPR

HETDEK

define input variables used in heat loss calculations

HEXCOR
find surface area contribution from rounded corners of multiperforated hexagonal propellant grain

HEXOSL
find surface area contribution for outer slivers in multiperforated hexagonal propellant grain

HLRATE
calculate heat-loss rate from treatment of Black and Comenetz in Chap. 5, vol. 1 of NDRC hypervelocity report (See Reference [7])

IBHVG2
Interior Ballistics of High-Velocity Guns, 2nd version (main program unit)

IBPREP
initialization and setup for ballistic cycle

INFDEK
define miscellaneous input run variables

INITCP
calculate initial conditions for constant-pressure run

INITPR
define properties of air in chamber and initialize some integrals with primer information

INTBAL
initiate and control calculations for IB cycle and bore-evacuation phase

KMPAUX
print user-requested values in trajectory print form

KMPRN1
print details at current time step in interior ballistic cycle

KMPRN2
print details at current time step in evacuation phase

KMTRM1
establish values of variables representing the transition conditions checked by KUTMER in IB cycle

KMTRM2
establish values of variables representing the transition conditions checked by KUTMER in evacuation cycle

KUTMER
5-step Runge-Kutta ODE integrator with auto-adjustment of step size to achieve accumulation tolerances as well as transition and print conditions

LCHECK
check layer depths for consistency and find initial current-layer-exposed for each surface of nth grain

LDEFIN
calculate layer-transition depths bases on ratios

LIMITF
check whether any values set by FUNMIN are out-of-range

MAXDEK
define input variables for maximum pressure search

MGRATE
calculate mass-generation rates, energy-generation rate, and related derivatives in chamber and perfs

MINAUX
print user-requested values in parametric print form

MINPRT
compressed print parametric runs

MXBRPR
adjust single input variable to achieve desired maximum pressure

NEWEPS
reset double-sided integrator tolerance EPSL

NEWFLG

update flags and clean up after each print step

OUTDEK

define program-accessible output variables

PACKER

encode utiuty for input parsing routines

PAGCHK

begin new output page with appropriate headings when necessary

PARDEK

define input variables dealing with automatic parametric variation of desired run variables

PDSDEK

define input variables dealing with user-selected printing on parametric compressed print summary

PICKDT

compute maximum integration step size

POLYIN

compute the integral for mass of an object with a density changing linearly in coordinate x. For example, if the object had two dimensions L and W for planes 1 and 2 which are perpendicular to x, then the integral would be:

$$Mass = \int_{x_1}^{x_2} \left[L_1 + \frac{L_2 - L_1}{x_2 - x_1}(x - x_1) \right] \left[W_1 + \frac{W_2 - W_1}{x_2 - x_1}(x - x_1) \right] \left[\rho_1 + \frac{\rho_2 - \rho_1}{x_2 - x_1}(x - x_1) \right] dx.$$

PRIDEK

define input variables for primer

PRPDEK

define input variables for propellant description

PSTORE

store parameter values from matrix

RATIOS recalculate charge weights, projectile weight, or chamber volume based on input options and ratios

RDLINE read input card-image

RECDEK define input variables for gun recoil

REDOIT accept last integration step for constant pressure run or prepare for restart of last step

RESDEK define input variables for resistance profile

RESIST ıpute resistance pressure to projectile motion

RUNDAT define the machine precision limit; return a current date through DAYR and time thru TIMR (TIMR is highly system-dependent and has been commented out)

SAVDEK process $SAVE control cards

SETVAR set a variable VNAME to number in VALUE for parametric variation and search routines or retrives current contents

SHOTGO set a shot-start flag based on initial chamber pressures and prepares for first search for maximum pressure

SPECIN same purpose as POLYIN, but modified to accomodate a SLOT geometry

STASHD
move double precision number

STASHI
convert double precision to integer

STDPRP
set default propellant properties

STRTRD
define control cards, initialize page control, and common blocks

TDSDEK
define user-selectable trajectory print variables

THERMI
return thermodynamic information interpolated linearly on depth burned

TRJDEK
define program-accessible output variables

TRJSUM
print run summary through projectile exit

UPDATE
post-print-step update

UPDAUX
find current layer exposed for jth surface of ith grain

VENTPF
find dm/dt from perforations based on method of Robbins & Horst in ARBRL-MR-03295 (See Reference [4])

WRAPUP
is merely a program stub. Users may desire to include their own system clean-up commands, etc.

IV. ALGORITHM DESCRIPTIONS

A. Calculation of Mean Temperature and Pressure

By the First Law of Thermodynamics, we state the energy balance for the closed interior ballistic system at time t as

initial energy of gases = internal energy of gases + losses

where the loss term includes work done by and heat transfered from the system. In addition, we will assume the gaseous components always retain their identity and that they undergo no fur reactions after being generated. Using average values of specific heats over the tem- anges considered, we express this balance as

$$\sum_{i,j} m_{ij} c_{v_{ij}} T_{f_{ij}} + m_e c_{v_e} T_{f_e} = \left[\sum_{i,j} m_{ij} c_{v_{ij}} + m_e c_{v_e} \right] T_{mean} + L \tag{A.01}$$

which we solve for mean temperature

$$T_{mean} = \frac{\sum_{i,j} m_{ij} c_{v_{ij}} T_{f_{ij}} + m_e c_{v_e} T_{f_e} - L}{\sum_{i,j} m_{ij} c_{v_{ij}} + m_e c_{v_e}} \tag{A.02}$$

where the summations are taken over each surface j of every charge element i with the addition of a primer considered all burned at $t = 0$. From the definitions

$$\gamma \equiv c_p / c_v \tag{A.03}$$

$$c_p - c_v = R \tag{A.04}$$

$$F = RT_f \tag{A.05}$$

it follows that

$$c_v = \frac{F}{(\gamma - 1) T_f}. \tag{A.06}$$

Substituting this result into (A.02) and simplifying our notation somewhat we get

$$T_{mean} = \frac{\sum_b \frac{F_b m_b}{\gamma_b - 1} + \frac{F_e m_e}{\gamma_e - 1} - L}{\sum_b \frac{F_b m_b}{(\gamma_b - 1)T_{f_b}} + \frac{F_e m_e}{(\gamma_e - 1)T_{f_e}}} \qquad \text{(A.07)}$$

which, in the limit, becomes

$$T_{mean} = \frac{\sum_b \int \frac{F_b}{\gamma_b - 1} dm_b + \frac{F_e m_e}{\gamma_e - 1} - L}{\sum_b \int \frac{F_b}{(\gamma_b - 1)T_{f_b}} dm_b + \frac{F_e m_e}{(\gamma_e - 1)T_{f_e}}} \qquad \text{(A.08)}$$

for differential weights burned, or

$$T_{mean}(t) = \frac{\sum_b \int \frac{F_b \dot{m}_b}{\gamma_b - 1} dt + \frac{F_e m_e}{\gamma_e - 1} - L(t)}{\sum_b \int \frac{F_b \dot{m}_b}{(\gamma_b - 1)T_{f_b}} dt + \frac{F_e m_e}{(\gamma_e - 1)T_{f_e}}} \qquad \text{(A.09)}$$

for instantaneous values of F, $\dot{m}$, γ, and T_f. The derivation of L is discussed in section III.D.

We assume Noble-Abel gases and mixtures, that is, a covolume correction applied to the ideal gas law so, at time t,

$$P_{mean}\left[V_{free} - \sum_b m_b \eta_b - m_e \eta_e\right] = \left[\sum_b m_b R_b + m_e R_e\right] T_{mean} \qquad \text{(A.10)}$$

which, with the aid of (A.05), we solve for mean pressure,

$$P_{mean} = \frac{T_{mean}\left[\sum_b \frac{F_b m_b}{T_{f_b}} + \frac{F_e m_e}{T_{f_e}}\right]}{V_{free} - \sum_b m_b \eta_b - m_e \eta_e} \qquad \text{(A.11)}$$

which becomes

$$P_{mean} = \frac{T_{mean}\left[\sum_b \int \frac{F_b}{T_{f_b}} dm_b + \frac{F_e m_e}{T_{f_e}}\right]}{V_{free} - \sum_b \int \eta_b dm_b - \eta_e m_e} \qquad \text{(A.12)}$$

in the limit for differential weights burned. The free volume of the system is the volume behind the projectile less that occupied by unburned propellant, or

$$V_{free} = V_c + A_b\left[x_p + x_r\right] - \sum_i n_i V_i \tag{A.13}$$

so

$$P_{mean}(t) = \frac{T_{mean}(t)\left[\sum_k \int \frac{F_k \dot{m}_k}{T_{f_k}} dt + \frac{F_e m_e}{T_{f_e}}\right]}{V_c + A_b\left[x_p + x_r\right] - \sum_i n_i V_i - \sum_k \int \eta_k \dot{m}_k dt - \eta_e m_e} \tag{A.14}$$

for instantaneous values of x_p, x_r, η, F, $\dot{m}$, γ, and T_f. The gun coordinate system defining the displacements x_p and x_r is shown in Figure 6. How they are computed is taken up in section III.B.

The rate at which the weight of propellant i is converted into gas on its jth surface is given by

$$\dot{m}_{ij} = n_i \rho_{ij} S_{ij} r_{ij} \tag{A.15}$$

for instantaneous values of ρ and S where the burning rates are either tabulated experimental values or empirical functions of the form

$$r_{ij} = \beta_{ij}\left[P_{mean}\right]^{\alpha_{ij}} + \varsigma_i v_p \tag{A.16}$$

for known α, β, and ς. The determination of the geometrical properties of individual propellant grains, V_i, S_{ij}, and n_i is taken up in section III.E.

B. Dynamic Relations

By Newton's Second Law, we express the acceleration of the projectile at any time t by

$$\text{projectile acceleration} = \frac{\text{net force on projectile}}{\text{projectile mass}}$$

where the propulsive force is supplied by the pressure of the propellant combustion gases on the base of the projectile and the retarding forces are provided by barrel resistance against the rotating band as well as air resistance against the nose as the air is compressed ahead of the projectile during its flight downtube. Hence we express projectile acceleration as

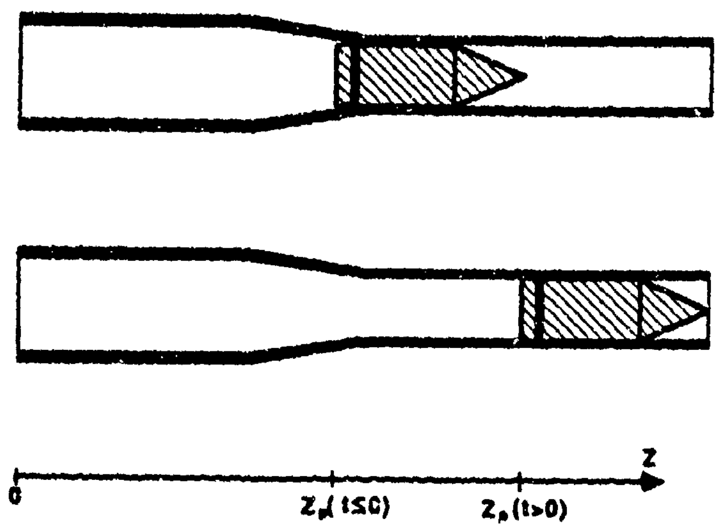


Figure 6. Gun Tube Reference Frame

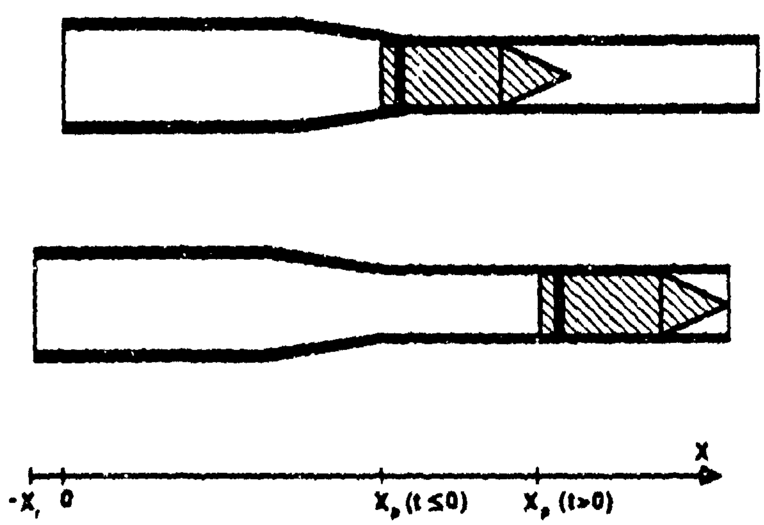


Figure 7. Ground Reference Frame

$$\ddot{x}_p = \frac{\left[P_{base} - P_{res} - P_{air}\right] A_b}{m_p/g} \tag{B.01}$$

for instantaneous values of P_{base}, P_{res}, and P_{air}. Similarly, the acceleration of the freely-recoiling barrel is

$$\ddot{x}_r = \frac{\left[P_{breech} - P_{res}\right] A_b}{m_r/g} \tag{B.02}$$

for instantaneous values of P_{breech} and P_{res}. One integration produces the ground-referenced projectile and recoil velocities $\dot{x}_p$ and $\dot{x}_r$. A second integration yields the projectile and barrel displacements, x_p and x_r, measured from their respective initial positions. Calculations of breech and base pressure are taken up in section III.C. Resistance pressure due to engraving of the rotating band is interpolated from tabular resistance pressures as a function of the tube-referenced projectile displacement $x_p + x_r$.

C. Calculation of the Pressure Gradient

We will consider two ways of calculating the pressure gradient in the system from the breech to the projectile base. The first is the so-called Lagrange approximation with the added assumption that the introduction of recoil does not appreciably disturb the gradient so derived. The central assumptions of this model are that the entire charge may at any time be treated as gaseous—that is, all burned—and that the density of the gas is uniformly distributed along the gun tube at any given time. The derivation in a tube-based frame of reference is as follows ($z_p \equiv x_p + x_r$).

We use the one-dimensional, inviscid equations of continuity and momentum

$$0 = \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial z}(\rho v), \qquad 0 \le z \le z_p \tag{C.01}$$

$$-\frac{1}{\rho}\frac{\partial P}{\partial z} = \frac{\partial v}{\partial t} + v\frac{\partial v}{\partial z}, \qquad 0 \le z \le z_p \tag{C.02}$$

together with the uniformity assumption

$$\frac{\partial \rho}{\partial z} = 0. \tag{C.03}$$

Then (C.01) and (C.03) imply

$$\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{d\rho}{dt} \tag{C.04}$$

with the boundary conditions of

$$v(0, t) = 0$$
$$v(z_p, t) = v_p \equiv \dot{z}_p \tag{C.05}$$

where z_p and v_p denote position of the projectile base and projectile velocity, respectively. Integrating over z, produces the gas velocity distribution

$$v(z, t) = z \frac{\dot{z}_p(t)}{z_p(t)} \tag{C.06}$$

indicating a linear distribution from breech to base. Substituting (C.06) into (C.02) we find

$$-\frac{1}{\rho}\frac{\partial P}{\partial z} = z \frac{z_p \ddot{z}_p - \dot{z}_p \dot{z}_p}{z_p^2} + \left[z \frac{\dot{z}_p}{z_p}\right]\left[\frac{\dot{z}_p}{z_p}\right] \tag{C.07}$$

or

$$\frac{\partial P}{\partial z} = -\rho \frac{z}{z_p} \ddot{z}_p. \tag{C.08}$$

Now the all-burnt assumption implies the (spatially uniform) density

$$\rho = \frac{\sum C_i / g}{A_b z_p}. \tag{C.09}$$

Substituting both (C.09) and (B.01) rewritten in tube-based coordinates into (C.08), we find

$$\frac{\partial P}{\partial z} = -\frac{z}{z_p}\left[\frac{\sum C_i / g}{A_b z_p}\right] \frac{\left[P_{base} - P_{res} - P_{air}\right] A_b}{m_p / g} \tag{C.10}$$

so that

$$P(z, t) = \psi(t) - \frac{\left[P_{base} - P_{res} - P_{air}\right] \sum C_i}{2 m_p z_p^2} z^2. \tag{C.11}$$

The condition $P(0, t) = P_{breech}$ implies

$$\psi(t) = P_{breech} \tag{C.12}$$

so the requirement $P(z_p, t) = P_{base}$ forces

$$P_{breech} = P_{base} + \frac{1}{2}\frac{\sum C_i}{m_p}\left[P_{base} - P_{res} - P_{air}\right]. \tag{C.13}$$

Into the definition

$$P_{mean} = \frac{1}{z_p}\int_0^{z_p} P(z,t)\,dz \tag{C.14}$$

we substitute (C.11) and (C.12) and integrate, yielding

$$P_{mean} = P_{breech} - \frac{1}{6}\frac{\sum C_i}{m_p}\left[P_{base} - P_{res} - P_{air}\right]. \tag{C.15}$$

Then substituting for P_{breech} from (C.13) into (C.15) and rearranging, we find

$$P_{base} \approx \frac{3\,P_{mean} + \frac{\sum C_i}{m_p}\left[P_{res} + P_{air}\right]}{3 + \frac{\sum C_i}{m_p}}. \tag{C.16}$$

Thus, according to the Lagrange model, knowledge of the charge-to-projectile weight ratio, the mean pressure, and the resistance pressures is sufficient to calculate the entire pressure gradient down the tube and, in particular, the desired base and breech pressures. Alternatively, the Pidduck-Kent gradient model may be employed.

The Pidduck-Kent model, as described by Corner[5], employs charge-to-mass ratio, Θ, specific heat ratio, γ, and space-mean pressure, P_{mean}, to estimate base and breech pressures in the ballistic gun system. The base pressure is scaled by the following:

$$\Theta \equiv \frac{\sum C_i}{m_p} \tag{C.17}$$

$$P_{base} = \frac{P_{mean}}{1+\frac{\Theta}{\Delta}} \tag{C.18}$$

where Δ is the Pidduck-Kent constant. Breech pressure is related to the base pressure estimate. Let

$$p \equiv \frac{1}{\gamma - 1} \tag{C.19}$$

$$\frac{1}{a_0} \equiv \frac{2p+3}{\Delta} + 2\frac{p+1}{\Theta}. \tag{C.20}$$

$$P_{breech} = P_{base}\left(1-a_0\right)^{n+1}. \tag{C.27}$$

The reader is encouraged to examine the classical derivation and its implicit assumptions for more information. The purpose here is to merely illustrate how IBHVG2 performs the calculations.

The Pidduck-Kent constant has been correlated with Θ and γ by a linear least squares fit described by Grollman and Baer[9]. No explanation was given for the formulation, but it is a fifth-order polynomial in charge-to-mass ratio and scaled with the specific heat ratio:

$$\Delta(\Theta) = 3+a\,\Theta+b\,\Theta^2+c\,\Theta^3+d\,\Theta^4+e\,\Theta^5 \tag{C.21}$$

where

$$a = a_1+\frac{a_2}{\gamma}, \quad b = b_1+\frac{b_2}{\gamma}, \quad \cdots, \quad e = e_1+\frac{e_2}{\gamma}. \tag{C.18}$$

Values for the fitted parameters $(a_1, a_2, b_1, b_2 ...)$ are given in the above reference. Not surprisingly with ten parameters, the regression error is quite small. The report states that the maximum error was 0.21% over the rectangular domain of $\gamma \in [\,1.2\,,\,1.3\,]$ and $\Theta \in [\,0\,,\,26\,]$. This is more than adequate for modeling considerations.

D. Work and Losses

The term $L(t)$ in (A.09) comprises the total work done by the interior ballistic system less the energy transfered from the system at time t. In IBHVG2, $L(t)$ includes contributions from: the translational kinetic energy of the projectile, the translational kinetic energy of the propellants and gases, the rotational kinetic energy of the projectile, the kinetic energy of the recoiling barrel, work done against barrel friction, work done against the resistance of the air in the tube opposing projectile motion, and heat lost to the gun tube. We neglect the amount of energy expended in the deformation of the gun barrel and any work done in overcoming the frictional resistance of the propellant bed or the combustion gases moving against the tube wall.

The translational kinetic energy of the projectile in a tube reference frame is

$$E_{trans} = \frac{1}{2}\,\frac{m_p}{g}\,\dot{z}_p^2. \tag{D.01}$$

To find the translational energy of the propellants and gases, we first consider the Lagrange model developed in section C. In this case, all the propellant was assumed to be burned, an assumption which implies there is no work expended in moving any solid propellant, only work done moving gases. Alternatively, we may reinterpret the assumption as requiring the solid propellant remaining at any instant to have the same linear velocity profile as the gases and be distributed throughout the system so that the overall density is uniform.

Either view is consistent with the expression for energy in a differential volume of the system

$$dE_{prop} = \frac{1}{2}\rho v^2(z)\,dV\,, \qquad 0 \le z \le z_p. \tag{D.02}$$

But the velocity at any point was found by (C.06), so

$$E_{prop} = \frac{1}{2}\rho A_b \int_0^{z_p} \left[z\,\frac{\dot{z}_p}{z_p} \right]^2 dz. \tag{D.03}$$

Integrating yields

$$E_{prop} = \frac{1}{6}\rho A_b z_p \dot{z}_p{}^2 \tag{D.04}$$

or, by substituting for ρ from (C.09) we have, with respect to the ground,

$$E_{prop} = \frac{1}{6}\,\frac{\sum C_i}{g}\,\dot{z}_p^2. \tag{D.05}$$

Similarly, it can be shown that for the Pidduck-Kent gradient model,

$$E_{prop} = \frac{1}{2}\,\frac{\sum_b \int \dot{m}_b\,dt + m_e}{\Delta g\,\dot{z}_p^2}. \tag{D.06}$$

The rotational kinetic energy of the projectile in a tube frame of reference is

$$E_{rotat} = \frac{1}{2} I_p \omega_p^2 \tag{D.07}$$

where the moment of inertia of the projectile is taken to be that of a solid cylinder of bore diameter and uniform density, that is

$$I_p = \frac{1}{8}\,\frac{m_p}{g}\,D_b^2. \tag{D.08}$$

Because of varying weight distribution, saboted projectiles have a smaller I_p than this while artillery shells have a larger I_p, but the fraction of overall energy embodied in E_{rotat} is so small that IBHVG2 currently assumes (D.08) for all projectiles. The twist for rifled barrels, τ, is commonly expressed as the number of "calibers" (barrel diameters) of downtube travel required for one complete revolution of the projectile. Thus, 2π radians are turned in τD_b inches of travel, so the definition

$$\theta_p = \omega_p t \tag{D.09}$$

implies

$$2\pi = \omega_p \left[\frac{\tau D_b}{\dot{z}_p} \right] \tag{D.10}$$

or, finally,

$$\omega_p(t) = \frac{2\pi \dot{z}_p}{\tau D_b}. \tag{D.11}$$

The translational energy of the recoiling barrel in a ground-based reference frame is

$$E_r = \frac{1}{2} \frac{m_r}{g} \dot{x}_r^2. \tag{D.12}$$

Currently, IBHVG2 requires tabular input of barrel frictional resistance pressure as a function of projectile displacement to compute the work done. These resistance profiles have been experimentally determined from measurements of force required to push projectiles through gun tubes or, perhaps more realistically, via instrumented projectiles used in actual firings which transmit data from onboard accelerometers and pressure gages. Given such tabular data, $P_{res}(z)$, the work required to overcome the frictional resistance of the gun tube is

$$E_{frict} = A_b \int_{z_p(0)}^{z_p} P_{res}(z)\,dz \tag{D.13}$$

where displacement is measured with respect to the barrel, or

$$E_{frict} = A_b \int \left[\dot{x}_p + \dot{x}_r \right] P_{res}(x_p + x_r)\,dt. \tag{D.14}$$

Similarly, the work done against air resistance is

$$E_{drag} = A_b \int \dot{z}_p P_{air}\,dt. \tag{D.15}$$

The last energy loss considered is that due to heat transfer to the gun barrel. The model employs a metal shell of thickness δ which is initially at temperature T_0 surrounding the interior ballistic system. As heat is transfered to the shell via convection from the combustion gases, it is assumed to come to thermal equilibrium instantaneously not only radially, but axially as the motion of the projectile exposes greater portions of the shell to heating. The rate of heat transfer is taken to be proportional to the difference between the mean temperature of the system, T_{mean}, and the average temperature of the shell, T_w, by Newton's Law of Cooling. That is,

$$E_{heat} = \int \dot{Q}\, dt \tag{D.16}$$

with

$$\dot{Q} = A_w h \left[T_{mean} - T_w\right] \tag{D.17}$$

where the wall area of the shell exposed to the system is that of the chamber plus that which has been exposed by the motion of the projectile, or

$$A_w = \left[\frac{V_c}{A_b}\right]\pi D_b + 2A_b + \pi D_b\left[z_p + z_r\right] \tag{D.18}$$

and the heat transfer coefficient

$$h = \lambda \bar{c}_p \bar{\rho}\, \bar{v} + h_0 \tag{D.19}$$

is that of Nordheim, Soodak, and Nordheim[8] with the addition of a natural convective term, h_0, to allow heat transfer in the absence of projectile motion. In the work cited, the authors selected a friction factor of

$$\lambda = \left[13.2 + 4\log_{10}\left[2.54\, D_b\right]\right]^{-2} \tag{D.20}$$

based on studies with rifled and unrifled tubes. The mean gas velocity is

$$\bar{v} = \frac{1}{2}\left[\dot{z}_p + \dot{z}_r\right] \tag{D.21}$$

from the linear gas velocity distribution in the Lagrange model (C.06). The mean gas density is the total weight of propellant burned divided by the volume of the system, or

$$\bar{\rho} = \frac{\sum_k \int \dot{m}_k\, dt + m_i}{V_e}. \tag{D.22}$$

Now (A.03) and (A.06) imply

$$c_p = \frac{F\gamma}{(\gamma - 1)T_f} \tag{D.23}$$

so we take the charge-weight-burned weighted average

$$\overline{c_p} = \frac{\sum_k \int \frac{F_k \gamma_k \dot{m}_k}{(\gamma_k - 1) T_{f_k}} dt + \frac{F_s \gamma_s m_s}{(\gamma_s - 1) T_{f_s}}}{\sum_k \int \dot{m}_k \, dt + m_s}. \tag{D.24}$$

At any instant, the heat already transfered to the shell is

$$Q + f\ E_{frict} = c_{p_w} m_w \left[T_w - T_0 \right] \tag{D.25}$$

or

$$Q + f\ F_{frict} = c_{p_w} \rho_w A_w \delta \left[T_w - T_0 \right] \tag{D.26}$$

where f is that fraction of work done against bore friction which pre-heats the shell. Knowledge of the heat capacity, density, and thickness of the shell permit calculation of the temperature of the shell

$$T_w = \frac{Q + f\ E_{frict}}{c_{p_w} \rho_w A_w \delta} + T_0 . \tag{D.27}$$

E. Propellant Grain Geometry

The calculation of instantaneous surface area and burning rates allows us to approximate burned propellant volume during the current time step at any point during deflagration. Thus the mass generation rate of propellant gases may be obtained for subsequent calculations of pressurization behind the projectile. (See Equation A.15)

Up to five different propellants may be described by as many $PROP input decks. Each may have a different grain geometry, charge weight, burning rate characteristics, and other physical properties; each deck must be self-sufficient in describing its propellant. Later references use the parameter NTH to point to an individual deck (first propellant deck is NTH=1, etc.).

In IBHVG2, we include many of the conventional propellant grain geometries in the "form function" subroutines. These codes solve for current surface area (burned) volume for the differnt grain types shown in Table 1. Forms CORD, STAR, 1F SLOT, 7PF, 19PF, and MONO are all variations on a right circular cylinder. The special form functions (HEX, MONO, and GEN) will be described later in this section. Descriptions and drawings of the grain types are in Appendix B.

Table 1. Grain Types

cord	CORD
sphere	BALL or SPHR
slab	SLAB or RECT
pie-shaped	STAR or PIE
single-perf	1PF or 1P
slotted single-perf	SLOT
seven-perf	7PF or 7P
nineteen-perf cord	19PF or 19P
hexagonal	GHEX or HEX
nineteen-perf hexagonal	19HX or 19H
thirty-seven perf hex	37HX or 37H
monolithic n-perf	MONO
general undefined	GEN

Each geometry described to IBHVG2 requires a minimum of information: either absolute measurements, or one exact measurement and a combination of ratios to other surfaces. Incompatible measurements of perf diamters, grain diameter, and web distances will, in general, show up as a change in grain diameter. Using the geometry and density, we calculate a unit weight for one grain, then we find the number of grains for the charge by dividing the unit weight into the charge weight.

As an example, for a i^{th} propellant of cord-type grains, each of initial length l_i, density ρ_i, and initial diameter D_i, we compute the initial volume V_i and number of grains n_i by

$$V_i = \pi l_i \left(\frac{D_i}{2}\right)^2 \qquad \text{(E.01)}$$

and

$$n_i = \frac{C_i}{V_i \rho_i} \qquad \text{(E.02)}$$

Total initial surface area S_i as the sum of lateral and end areas is

$$S_i = \pi n_i \left[D_i l_i + 2 \left(\frac{D_i}{2} \right)^2 \right] \qquad \text{(E.03)}$$

We assume all propellant burns in a direction perpendicular to the grain surface. During the current time step, a laminar layer is consumed which has total volume V_i^* approximated by

$$V_i^* = n_i S_i \epsilon_i, \qquad \text{(E.04)}$$

where ϵ_i is the depth burned during the step. As long as the time increment is small and no gross change of grain geometry occurs during the step, then we may use V^* to calculate pressure increase. Each physical dimension affected by the loss of solid propellant is updated before the next time step, when surface and remaining volume are recalculated. For generality, we may define the lateral surfaces with a specific burning rate function, the end surfaces with a second burning rate, and a third function for any perforation surfaces.

If a major change occurs in the propellant geometry, as in this case when current grain diameter is D_i^* and

$$D_i^* \leq 2\epsilon_i, \qquad \text{(E.05)}$$

then the grain has extinguished and all remaining volume has burned. IBHVG2 checks for this and similar cases on `rent grain types; the appropriate time step is d creased to find the exact time where geon y is flagged, and an output line is printed to notify the user.

All multiperforated grains develop fragments when depth burned reaches one-half web distance. The method of calculation differentiates between inner and outer slivers, as described in Reference [10].

HEX is a general form for right hexagonal grains. The geometry assumes at least one central perforation; additional perforations are described by a value for NRNG. NRNG=1 will provide a seven-perforated hexagonal grain; NRNG=2 will be a nineteen-perf hexagonal grain. The number of perforations possible is theoretically unlimited. Web distance is a required input; perforation diameter and grain length may be described directly or as ratios to given dimensions. Major diameter is computed from a combination of web distances and perforation diameters.

We atte pt to generalize the right circular cylindrical grain for more than nineteen perforations the type MONO. This is an experimental grain type currently under consideration. The idea sed on the catalytic monoliths currently found in automobile mufflers to reduce air pollut It is hoped that recent advances in extrusion technology used to make the ceramic catalytic monoliths can be transferred to propellant manufacture. The concept is novel because the dimensions are on the order of the diameter of the gun tube. Conceptually, there is no difference in modeling this type of grain than a standard multi-perfed grain. The grain length, web distance, and diameters (perforation and grain) are required inputs. The routine will calculate the number of perforations consistent with the given dimensions.

We have a user-definable f unction, GEN, in the guise of two input arrays containing data pairs describing depth burned versus total surface area of propellant grains. This allows use of irregularly shaped grain forms as long as the user can describe the surface function. Test case 2 found in Appendix C demonstrates the use of a general form function approximating a 7-perf geometry.

Often real propellants are made in a series of layers. For example, an outer layer may consist of a thin, slow-burning layer applied over a fast-burning central propellant core. Each propellant geometry must have a core layer (designated as layer 4), and may have up to three more layers. The depth of the transitions between layers is order-dependent in the input deck description, with associated burning rates, densities, and other physical properties similarly defined. IBHVG2 keeps track of these layers during the deflagration process and signals to the user when each transition has been accomplished. Variation of density in grain layers affect grain weight so that for the i^{th} propellant having j distinct layers, Equation (E.02) becomes

$$n_i = \frac{C_i}{\sum_j V_{ij} \rho_{ij}} . \qquad \text{(E.06)}$$

V. APPENDICES

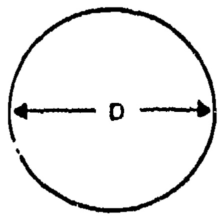
A. Nomenclature

Symbol	Definition	Units
α	exponent in burning-rate expression	*varies*
β	coefficient in burning-rate expression	*varies*
γ	specific heat ratio, c_p/c_v	—
δ	wall shell thickness	*in*
Δ	Pidduck-Kent constant	—
ϵ	distance burned into propellant	*in*
η	propellant covolume	in^3/lb_m
λ	friction factor	—
ω	rotational distance	*radians*
ρ	density	lb_m/in^3
τ	gun tube rifling	*calibers* $/2\pi$
θ	angle of rotation	*radians*
Θ	charge/projectile mass ratio	—
ζ	burning rate augmentation factor	—
a, b, c, d, e	Pidduck-Kent coefficients	—
c_p	specific heat at constant pressure	$in\ lb_f\ lb_m^{-1}\ {}^\circ K^{-1}$
c_v	specific heat at constant volume	$in\ lb_f\ lb_m^{-1}\ {}^\circ K^{-1}$
f	fraction of friction work converted to heating the tube	—
g	acceleration due to gravity	in/sec^2
h	heat transfer coefficient	$lb_f\ ft^{-1}\ {}^\circ K^{-1}$
l	length	*in*
m	charge weight	lb_m
n	number of propellant grains	—
p	Pidduck-Kent parameter	—
r	propellant regression rate	in/sec
t	time	*sec*
v	velocity	in/sec
x	travel coordinate, ground reference frame	*in*
z	travel coordinate, tube reference frame	*in*
A	area	in^2
C	unburnt propellant	lb_m
D	diameter	*in*
E	energy	$ft\ lb_f$

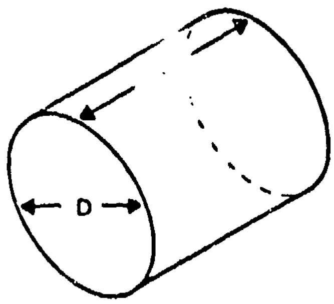
Symbol	Definition	Units
F	propellant "force"	$ft\ lb_f/lb_m$
I	moment of inertia	$lb_m\ in^2$
L	energy losses	$ft\ lb_f$
P	pressure	lb_f/in^2
Q	heat loss	$ft-lb_f$
R	universal gas constant	$ft\ lb_f mole^{-1}\ {}^{\circ}K^{-1}$
T	temperature	$^{\circ}K$
V	volume	in^3

Subscript	Definition
air	property due to air in gun tube
b	bore
base	base of projectile
breech	breech of gun chamber
c	chamber
drag	resistance to motion
f	flame property
free	available space for propellant gases
frict	frictional property
heat	heat-induced property
i	propellant charge number
j	propellant grain surface
k	propellant type w.r.t. chemical/energetic properties
mean	averaged property
p	projectile
prop	propellant
r	recoil
res	frictional resistance
rotat	rotational property
s	primer property
trans	translational
v	free volume
w	wall property
ϕ	initial

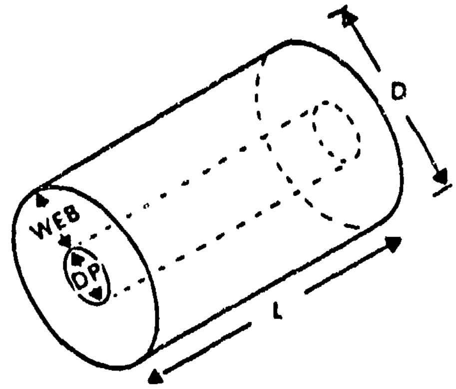
B. Propellant Grain Configurations



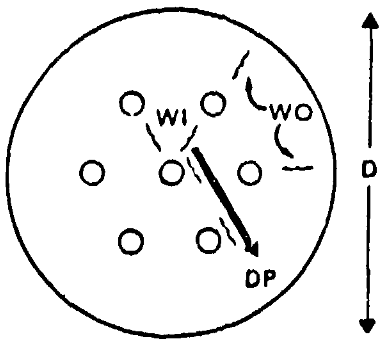
Ball



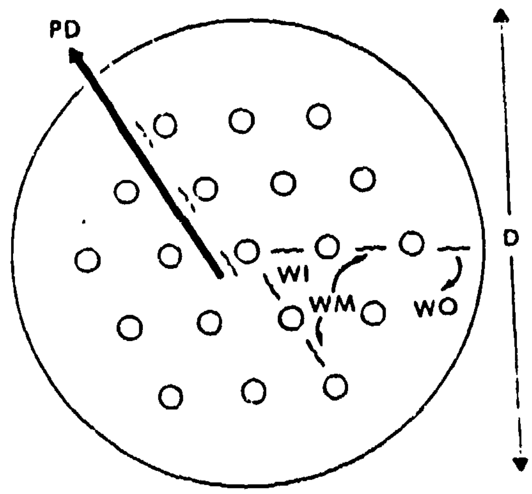
Cord



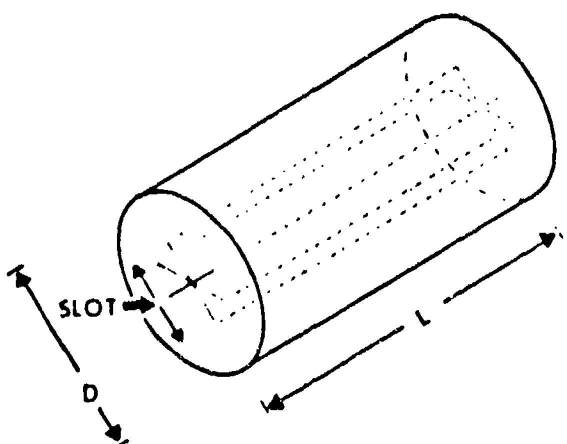
Single-Perf



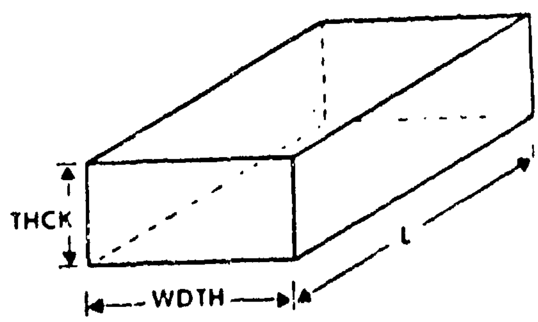
7-Perf



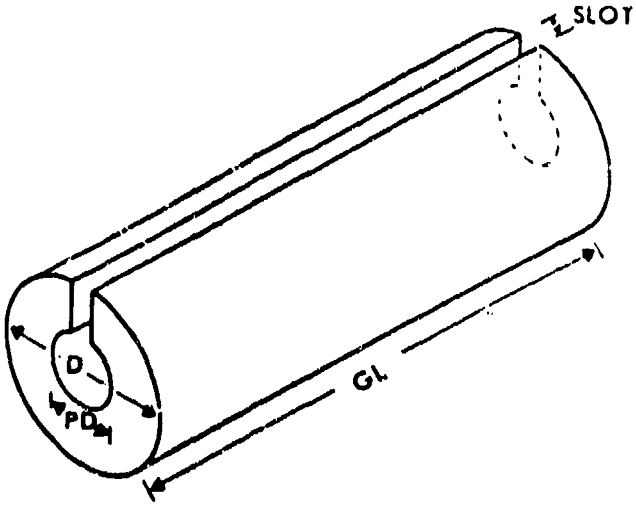
19-Perf



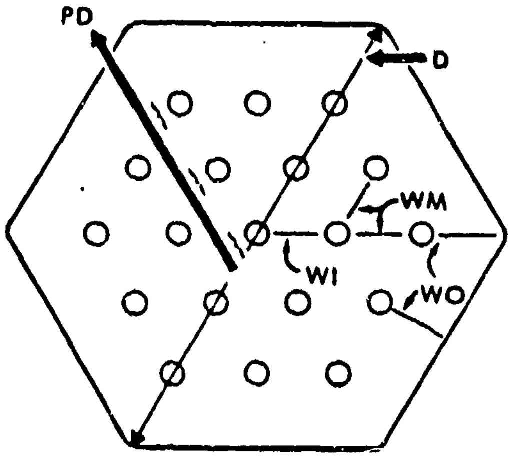
Pie (showing NSLT=3)



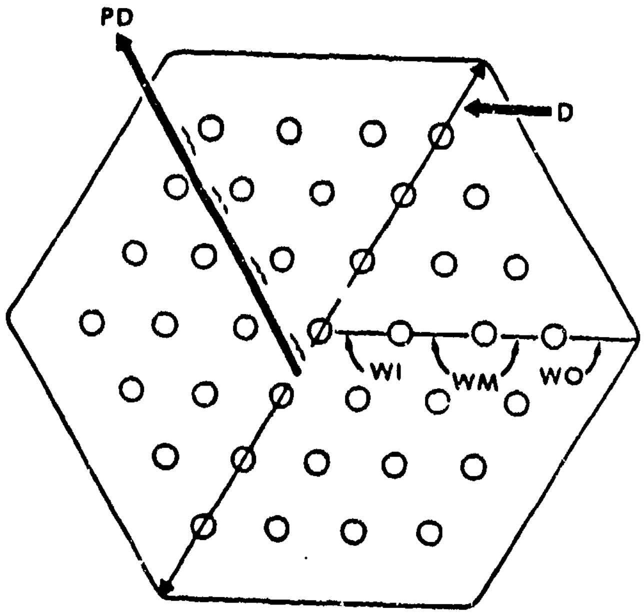
Strip (Rectangular)



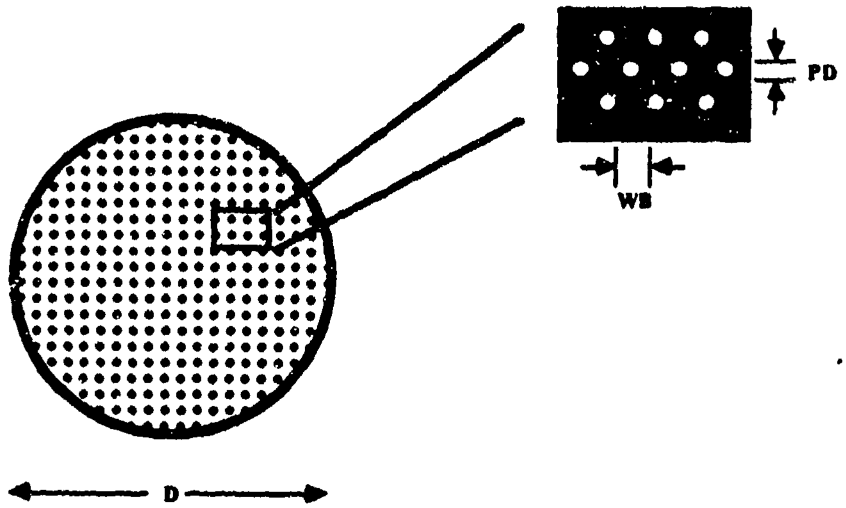
Slotted Stick



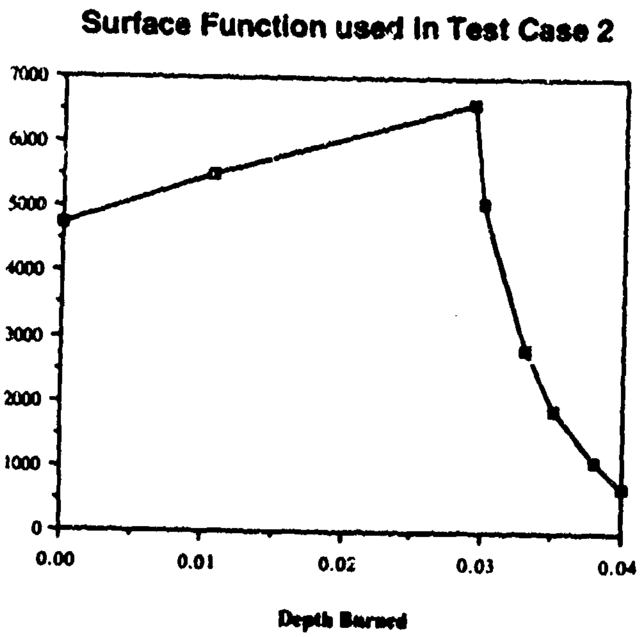
19-Perf, Hexagonal



37-Perf, Hexagonal



Monolithic



General

C. Installation

IBHVG2 (Version 400 and higher) has been re-designed for use with computers having no less than a 32-bit word length. Although the software may run on a shorter word-length machine, the precision of the output and ease of use will suffer greatly since the default tolerances require at least five significant digits. For example, the default pressure tolerance on a PMAX calculation is 1 psi, and normal pressure ranges are 10 kpsi and higher for most calculations. Therefore, a computer which does not have five decimal digits accuracy cannot reliably solve for pressure within default tolerance.

The first line of output from IBHVG2.400 is a CPU-dependent indicator of the attainable accuracy of a floating-point computation. The code computes the "machine epsilon" as commonly defined in numerical analysis. The pseudo-code shown below illustrates both the definition and the implementation.

$i \leftarrow 0$
repeat
  $i \leftarrow i+1$
  $\epsilon \leftarrow 2^{-i}$
until $(1.0 \geq 1.0 + \epsilon)$

The value of ϵ which terminates the loop is printed and saved in variable ERRTOL. It is typically on the order of 10^{-7} on 32-bit computers and 10^{-15} on 64-bit systems. ERRTOL is used for deciding when iterative solutions have converged to within the precision of a given machine.

IBHVG2.400 has been benchmarked and tested on computers using the FORTRAN66 and FORTRAN77 compilers. Some non-portable FORTRAN exists in the code and a description follows:

Main Program IBHVG

The PROGRAM statement is required to define I/O parameters in certain systems, while others only need to define the entry point. For the former, I/O devices are:

#	Unit Name	Description
5	NDEVI	Standard Input device
6	NDEVO	Standard Output device
7	NDEVS	When $INFO deck option SOPT=1 or 2, this device saves output copy for user-supplied post-processing
9	NDEVT	Temporary character-manipulation device

All are formatted I/O devices, as opposed to unformatted binary files. NOTE: On many systems, more than one run may execute at any given time. Be sure that the separate runs do not overlap on I/O devices.

Subroutine CRKNUM

IBHVG2 writes characters, integers, and floating-point numbers to NDEVT and reads them back later for format conversion; CRKNUM handles the character-to-number conversion process. Since some operating systems use only upper-case alphabetic characters, and others may use lower-case letters, a provision has been made to interpret 'e' and 'd' as 'E' and 'D' during the conversion. Variables SMALLE and SMALLD should contain the lower-case letters. While transferring source code between systems, these characters often are converted to upper-case unintentionally.

Subroutine HELPPR

Array HOLD is used for run-time format development. Many FORTRAN77 compilers require that HOLD be declared as a CHARACTER array; FORTRAN66 does not recognize the CHARACTER statement.

Subroutine RDLINE

Reads input line and prints copy to standard output device. RDLINE must recognize the situation when end-of-input is reached. FORTRAN66 and FORTRAN77 use different end-of-file routines; use one of the given examples or re-write to suit the compiler.

Subroutine RUNDAT

Contains most of the machine-dependent coding, including a section which can be used to insert current date and time (if available from the CPU). Array DAYR holds the date; array TIMR holds the time. The original program opted for a 'DD-MMM-YY' and 'HH:MM:SS' format, but can be put in any format which will fit in the 12-character arrays. The arrays will be printed at the top of each page, along with the current run title. This feature has been commented out in the distribution deck in order to obtain maximum compiler flexibility. A section of interactive control statements concerning availability of input/output files has been added for IBM/PC-AT users.

When compiling, non-fatal warnings may occur in FORTRAN77 because non-character arrays are being filled with alphanumeric information. Ignore them if possible. After compilation, link the object code with standard FORTRAN libraries (including SIN, COS, MOD, SQRT, etc.).

D. Bugs

Sometimes, a particular calculation will not converge due to the integration algorithm. This has not been fully explored, but an eject mechanism has been installed in the KUTMER subroutine to indicate an error whenever ballistic time does not advance in twenty integration steps. A common action to relieve the thrashing is to change the integration step size (DT in the $INFO deck). Because of this weakness in IBHVG2, one should monitor the calculations closely, observing that the solution is progressing, or one should use "time" cards or other time-limiting features of one's computer operating system to minimize endless computations. The integration routine is known to be suspect, and will be replaced in a future version.

IBHVG2 occasionally has serious problems with 37-perf propellant. The symptom is a sudden change in peak pressure and muzzle velocity with a tiny change in web dimension. It's almost as if, at the time of slivering, propellant gases come together to reform solid propellant. We are checking on this one; in the meantime, trust 37-perf simulations only after varying webs over a range around your final solution.

Due to the accuracy limitations of the integration routines, IBHVG2 will often seem to find successive pressure maximums and minimums when they do not co-exist in real situations. The overall maximums will be correctly reported in the end-of-trajectory summary. Extreme care must be taken if the user attempts to find values for the second (or later) pressure peaks (i.e., NPMX > 1 in the $PMAX deck) since the numeric fluctuations will be treated as actual pressure peaks.

Some users have had trouble with using the $FIND option. The problem can usually be traced to a poor initial guess to start off the optimization. The algorithm encoded is relatively weak and requires a better guess than perhaps more modern techniques. Therefore, we suggest that $FIND be used with knowledge of its limitations and to apply some caution. It would not be unreasonable to perform a $PARA iteration around the answer obtained with the $FIND just to make sure. If the option converges correctly for your particular problem, it has proven to be quite useful in charge design.

E. Sample Input Decks and Outputs

Sample input decks follow. The corresponding outputs are among the files on the distribution media. These were run on a Perkin-Elmer 3252 (32-bit word) running AT&T UNIX System V, Release 2.0 and compiled using the 'f77' compiler. The calculations match closely with those of a CDC 7600 running NOS (64-bit word). Other machines checked were: DEC VAX/780 running VMS, IBM PC/AT running MSDOS with floating point, DEC VAX/780 running UNIX 4.2 BSD, and Cray X/MP-48 running COS (64-bit word).

Below is a table showing some execution times of the different inputs on some representative hardware. We are trying to give an approximate feel for performance on a mainframe computer, a minicomputer, and a microcomputer. As one can readily see, the most appropriate environment depends on what type of problem you are involved with. If the code was to estimate the behavior of a given input (few iterations), then the microcomputer will deliver the answer in a minute or two. On the other hand, complex optimization problems can require minutes of mainframe time.

Case	CPU Time *(seconds)*		
	Cray X/MP-48	VAX 780	IBM PC/AT
1	0.4	26.4	93
2	0.7	38.5	122
3	4.7	267.4	1054
4	2.8	115.9	868
5	14.9	526.7	4912
6	13.5	634.8	3895

One interesting quirk which might be noticed by the reader is that the ordering of the run times is not consistent among the different machines. For example, case 5 took less time to compute on the Cyber and the PC than case 6, while the order is reverse on the VAX. This is caused by the precision of the arithmetic with the intermediate results. The Cray has a 64-bit word at single-precision and the PC's floating point processor computes to 80 bits; the VAX is using only 32 bits of precision. We speculate that there are some convergence problems for these cases which are causing more difficulty for the VAX than the other two machines. Ideally, the integration routine should recognize this and compensate accordingly, but this remains a future project.

Test Case 1

This input deck represents a minimum IBHVG2 run. The two methods of commenting input decks are shown ($COMM and after $ on any input card). Note that all the primer in the $PRIM deck is considered burnt at the start of calculation. A good practice for primer/igniter definition is to separate the igniter into two pieces so that a large amount of energetic material is not suddenly introduced into the gun chamber. One piece should be a $PRIM deck including just enough to ignite the rest of the primer as a $PROP deck. (Usually about 10 percent of the igniter in $PRIM seems to work well.) Also notice that the second propellant geometry input does not include a main diameter since it is calculated in the form function subroutine. Blank lines and other white space between input deck sections allow easy readability, but are not necessary.

```
$COMM
        IBHVG2 BENCHMARK TEST CASE 1

        HARP GUN WITH M30 PROP 7P

$INFO
       POPT=1,1,1,0   $  ECHO INPUT LINES, PRINT TRAJECTORY + SUMMARY
       RUN='M30 7-PERF - LOT UNKNOWN'

$GUN
       NAME='HARP GUN'
       CHAM=4378   GRVE=7.292   LAND=7.292  $ SMOOTH BORE
       TRAV=570.5  TWST=99

$COMMENT
       PRIMER IS ASSUMED ALL BURNED AT TIME=0.0
       IGNITER CHARGE IS PROPELLANT 1
       MAIN CHARGE IS PROPELLANT 2
$PRIM
       NAME='BLK POWDER'    CHWT=0.0154
       GAMA=1.25   FORC=96000   COV=30   TEMP=2000
$PROP
       NAME='BLK POWDER'    CHWT=1.5    GRAN='CORD'
       LEN=0.198   DIAM=0.098   RHO=0.06
       GAMA=1.25   FORC=96000   COV=35   TEMP=2000
       ALPH=0.0    BETA=20
$PROP
       NAME='M30 LOT UNKNOWN'    CHWT=55       GRAN='7PF'
       LEN=0.672    PD=0.026     WEB=0.0457   RHO=0.0607
       GAMA=1.2441  FORC=359876  COV=28.441   TEMP=3012
       NTBL=4   PR4L=6000,10000,12000,40000   BR4L=2.0,2.56,2.75,5.94

$COMMENT
       NOMINAL PROJECTILE AND RESISTANCE PROFILE
$PROJ
       NAME='PLASTIC LAB SABOT' PRWT=52
$RESI
       NPTS=4
       TRAV=0,   0.3,  3,   600
       PRES=100, 4000, 1800, 800
$END
```

Producing the following output:

```
ERRTOL=   4.768372E-07

CARD   1 --> $COMM
CARD   2 -->             IBHVG2 BENCHMARK TEST CASE 1
CARD   3 -->
CARD   4 -->             HARP GUN WITH M30 PROP 7P
CARD   5 -->
CARD   6 --> $INFO              $  ECHO INPUT LINES, PRINT TRAJECTORY + SUMMARY
CARD   7 -->            POPT=1,1,1,0
CARD   8 -->            RUN='M30 7-PERF - LOT UNKNOWN'
CARD   9 -->
CARD  10 --> $GUN
CARD  11 -->            NAME='HARP GUN'
CARD  12 -->            CHAM=4378   GRVE=7.292   LAND=7.292  $ SMOOTH BORE
CARD  13 -->            TRAV=570.5  TWST=99
CARD  14 -->
CARD  15 --> $COMMENT
CARD  16 -->            PRIMER IS ASSUMED ALL BURNED AT TIME=0.0
CARD  17 -->            IGNITER CHARGE IS PROPELLANT 1
CARD  18 -->            MAIN CHARGE IS PROPELLANT 2
CARD  19 --> $PRIM
CARD  20 -->            NAME='BLK POWDER'    CHWT=.0154
CARD  21 -->            GAMA=1.25    FORC=96000    COV=30    TEMP=2000
CARD  22 --> $PROP
CARD  23 -->            NAME='BLK POWDER'    CHWT=1.5    GRAN='COPD'
CARD  24 -->            LEN=.198     DIAM=.098    RHO=0.06
CARD  25 -->            GAMA=1.25    FORC=96000    COV=35    TEMP=2000
CARD  26 -->            ALPH=0.0     BETA=20
CARD  27 --> $PROP
CARD  28 -->            NAME='M30 LOT UNKNOWN'    CHWT=55       GRAN='7PF'
CARD  29 -->            LEN=.672      FU=.026      WEB=.0457     RHO=0.0607
CARD  30 -->            GAMA=1.2441  FORC=359876  COV=28.441    TEMP=3012
CARD  31 -->            NTBL=4   PR4L=6000,10000,12000,40000   BR4L=2.0,2.56,2.75,5.94
CARD  32 -->
CARD  33 --> $COMMENT
CARD  34 -->            NOMINAL PROJECTILE AND RESISTANCE PROFILE
CARD  35 --> $PROJ
CARD  36 -->            NAME='PLASTIC LAB SABOT' PRWT=52
CARD  37 --> $RESI
CARD  38 -->            NPTS=4
CARD  39 -->            TRAV=0,    .3,   3,    600
CARD  40 -->            PRES=100, 4000, 1800, 800
CARD  41 --> $END
```

```
-------------
- GUN TUBE -
-------------

 TYPE: HARP GUN                              CHAMBER VOLUME (IN3):          4378.00    TRAVEL (IN):                    570.50
 GROOVE DIAMETER (IN):          7.292        LAND DIAMETER (IN):               7.292    GROOVE/LAND RATIO (-):          0.000
 TWIST (CALS/TURN):              99.0        BORE AREA (IN2):                41.7622    HEAT-LOSS OPTION:                   1
 SHELL THICKNESS (IN):       0.004000        SHELL CP (IN-LB/LB-K):           1848.0    SHELL DENSITY (LB/IN3):         0.2840
 INITIAL SHELL TEMP (K):         293.        AIR HO (IN-LB/IN2-S-K):         0.06480

--------------
- PROJECTILE -
--------------

 TYPE: PLASTIC LAB SABOT                     TOTAL WEIGHT (LB):               52.000    WEIGHT PREDICTOR OPTION·            0

--------------
- RESISTANCE -
--------------

 AIR RESISTANCE OPTION:             1        WALL HEATING FRACTION:            0.000    FRICTION TABLE LENGTH:              4

  I   TRAVEL (IN)    PRESSURE (PSI)           I   TRAVEL (IN)    PRESSURE (PSI)          I   TRAVEL (IN)    PRESSURE (PSI)

  1      0.00            100.                 3      3.00          1800.                 4     600.00          800.
  2      0.30           4000.

-----------
- GENERAL -
-----------

 MAX TIME STEP (S):          0.000100        PRINT STEP (S):                0.000000    MAX RELATIVE ERROR (-):       0.00200
 PRINT OPTIONS:           1 1 1 0 1 1        STORE OPTION:                         0    CONSTANT-PRESSURE OPTION:           0
 GRADIENT MODEL: LAGRANGIAN

----------
- RECOIL -
----------

 RECOIL OPTION:                     0        TYPE:                                      RECOILING WEIGHT (LB):             0.

----------
- PRIMER -
----------

 TYPE: BLK POWDER                            GAMMA (-):                       1.2500    FORCE (FT-LB/LB):              96000.
 COVOLUME (IN3/LB):            30.000        FLAME TEMP (K):                  2000.0    WEIGHT (LB):                 0.015400
```

- CHARGE 1 -

TYPE: BLK POWDER		GRAINS:	16739.	CORD	WEIGHT (LB):	1.5000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.19800	GRAIN DIAMETER (IN):		0.09800		

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06000	------	------	------	0.06000
GAMMA (-):	------	------	------	1.2500	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	96000.	------	------	------	96000.
COVOLUME (IN3/LB):	------	------	------	35.000	------	------	------	35.000
FLAME TEMP (K):	------	------	------	2000.0	------	------	------	2000.0
BURNING RATE EXPS:	------	------	------	0.0000	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	20.0000000	------	------	------	20.0000000

- CHARGE 2 -

TYPE: M30 LOT UNKNOWN		GRAINS:	27128. 70°F	WEIGHT (LB):	55.0000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.67200	GRAIN DIAMETER (IN):	0.26080	PERF DIAMETER (IN):	0.02600
INNER WEB (IN):	0.04570	OUTER WEB (IN):	0.04570		

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06070
GAMMA (-):	------	------	------	1.2441
FORCE (FT-LB/LB):	------	------	------	359876.
COVOLUME (IN3/LB):	------	------	------	28.441
FLAME TEMP (K):	------	------	------	3012.0
MEAN PRESSURES (PSI):	------	------	------	6000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	12000.0
MEAN PRESSURES (PSI):	------	------	------	40000.0
BURNING RATES (IN/S):	------	------	------	2.00
BURNING RATES (IN/S):	------	------	------	2.56
BURNING RATES (IN/S):	------	------	------	2.75
BURNING RATES (IN/S):	------	------	------	5.94

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06070
GAMMA (-):	------	------	------	1.2441
FORCE (FT-LB/LB):	------	------	------	359876.
COVOLUME (IN3/LB):	------	------	------	28.441
FLAME TEMP (K):	------	------	------	3012.0
MEAN PRESSURES (PSI):	------	------	------	6000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	12000.0
MEAN PRESSURES (PSI):	------	------	------	40000.0
BURNING RATES (IN/S):	------	------	------	2.00
BURNING RATES (IN/S):	------	------	------	2.56
BURNING RATES (IN/S):	------	------	------	2.75
BURNING RATES (IN/S):	------	------	------	5.94

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06070
GAMMA (-):	------	------	------	1.2441
FORCE (FT-LB/LB):	------	------	------	359876.
COVOLUME (IN3/LB):	------	------	------	28.441
FLAME TEMP (K):	------	------	------	3012.0
MEAN PRESSURES (PSI):	------	------	------	6000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	12000.0
MEAN PRESSURES (PSI):	------	------	------	40000.0
BURNING RATES (IN/S):	------	------	------	2.00
BURNING RATES (IN/S):	------	------	------	2.56
BURNING RATES (IN/S):	------	------	------	2.75
BURNING RATES (IN/S):	------	------	------	5.94

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
0.000	0.00	0.	0.	5.	5.	5.	2000.	0.000	0.000
0.100	0.00	0.	0.	94.	94.	94.	2329.	0.099	0.001
0.106	0.00	0.	0.	100.	100.	100.	2337.	0.104	0.001
SHOT-START PRESSURE ACHIEVED									
0.200	0.00	0.	66.	227.	212.	182.	2432.	0.191	0.002
0.300	0.00	0.	147.	386.	353.	287.	2501.	0.277	0.003
0.400	0.00	1.	235.	567.	514.	408.	2554.	0.356	0.005
0.500	0.00	2.	327.	768.	694.	546.	2597.	0.431	0.007
0.600	0.01	3.	420.	986.	891.	702.	2634.	0.499	0.009
0.700	0.01	5.	511.	1221.	1106.	875.	2665.	0.562	0.012
0.800	0.02	6.	597.	1471.	1337.	1068.	2693.	0.620	0.015
0.900	0.03	8.	674.	1737.	1585.	1280.	2717.	0.673	0.018
1.000	0.04	11.	741.	2016.	1848.	1514.	2739.	0.720	0.021
1.100	[illegible]	13.	796.	2308.	2128.	1769.	2759.	0.764	0.025
1.200	[illegible]	16.	837.	2613.	2425.	2047.	2777.	0.803	0.029
1.300	0.09	19.	862.	2931.	2737.	2348.	2793.	0.838	0.033
1.400	0.11	21.	872.	3262.	3065.	2672.	2808.	0.868	0.037
1.500	0.14	24.	865.	3605.	3410.	3020.	2822.	0.895	0.042
1.600	0.17	27.	842.	3961.	3771.	3391.	2834.	0.919	0.047
1.700	0.21	30.	804.	4330.	4149.	3786.	2846.	0.938	0.052
1.800	0.24	32.	753.	4713.	4543.	4203.	2857.	0.955	0.058
1.900	0.28	34.	689.	5110.	4954.	4643.	2867.	0.969	0.064
2.000	0.33	37.	827.	5569.	5383.	5009.	2876.	0.980	0.070
2.100	0.37	40.	1112.	6079.	5828.	5327.	2884.	0.988	0.076
2.200	0.42	44.	1409.	6610.	6292.	5656.	2892.	0.994	0.082
2.300	0.48	49.	1719.	7160.	6773.	5997.	2899.	0.998	0.089
2.400	0.54	55.	2043.	7732.	7271.	6350.	2906.	1.000	0.096
2.450	0.57	58.	2211.	8026.	7527.	6530.	2909.	1.000	0.100
PROPELLANT 1 BURNED OUT									
2.500	0.61	62.	2382.	8325.	7788.	6714.	2911.	1.000	0.103
2.600	0.69	70.	2735.	8940.	8323.	7090.	2917.	1.000	0.111
2.700	0.78	80.	3105.	9578.	8877.	7477.	2922.	1.000	0.119
2.800	0.88	90.	3491.	10237.	9450.	7875.	2926.	1.000	0.127
2.900	1.00	102.	3895.	10919.	10041.	8284.	2929.	1.000	0.135
3.000	1.13	115.	4315.	11621.	10648.	8701.	2932.	1.000	0.144
3.100	1.27	130.	4752.	12340.	11268.	9125.	2935.	1.000	0.153
3.200	1.44	146.	5205.	13076.	11902.	9555.	2937.	1.000	0.162
3.300	1.63	164.	5677.	13833.	12552.	9991.	2939.	1.000	0.172
3.400	1.83	183.	6172.	14615.	13223.	10439.	2940.	1.000	0.181
3.500	2.07	203.	6690.	15423.	13914.	10896.	2941.	1.000	0.192
3.600	2.32	226.	7233.	16257.	14626.	11363.	2941.	1.000	0.202
3.700	2.61	250.	7801.	17116.	15356.	11838.	2941.	1.000	0.213
3.800	2.92	276.	8394.	17999.	16106.	12319.	2941.	1.000	0.225
3.900	3.27	304.	8882.	18876.	16873.	12866.	2940.	1.000	0.236
4.000	3.65	333.	9344.	19763.	17656.	13441.	2939.	1.000	0.249
4.100	4.07	364.	9815.	20648.	18456.	14027.	2938.	1.000	0.261
4.200	4.53	396.	10294.	21589.	19267.	14624.	2936.	1.000	0.274
4.300	5.02	430.	10780.	22523.	20092.	15229.	2934.	1.000	0.288
4.400	5.56	466.	11273.	23471.	20928.	15843.	2931.	1.000	0.302
4.500	6.14	503.	11771.	24428.	21773.	16463.	2928.	1.000	0.316
4.600	6.77	542.	12274.	25394.	22626.	17089.	2925.	1.000	0.331
4.700	7.44	582.	12779.	26366.	23483.	17719.	2921.	1.000	0.346
4.800	8.17	624.	13287.	27341.	24344.	18351.	2917.	1.000	0.362
4.900	8.94	668.	13795.	28318.	25207.	18984.	2912.	1.000	0.378
5.000	9.77	713.	14302.	29293.	26067.	19616.	2907.	1.000	0.395

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
5.100	10.65	760.	14808.	30264.	26925.	20245.	2902.	1.000	0.412
5.200	11.59	808.	15309.	31229.	27776.	20870.	2897.	1.000	0.429
5.300	12.59	858.	15806.	32184.	28619.	21489.	2891.	1.000	0.447
5.400	13.65	910.	16296.	33126.	29450.	22099.	2885.	1.000	0.466
5.500	14.78	963.	16779.	34053.	30269.	22700.	2879.	1.000	0.485
5.600	15.97	1018.	17252.	34963.	31072.	23290.	2872.	1.000	0.504
5.700	17.22	1074.	17714.	35852.	31857.	23866.	2865.	1.000	0.524
5.800	18.55	1132.	18164.	36718.	32621.	24427.	2858.	1.000	0.544
5.900	19.94	1191.	18601.	37558.	33363.	24972.	2851.	1.000	0.565
6.000	21.41	1252.	19024.	38371.	34080.	25499.	2843.	1.000	0.586
6.100	22.94	1314.	19431.	39154.	34771.	26006.	2836.	1.000	0.607
6.200	24.56	1377.	19821.	39905.	35434.	26493.	2828.	1.000	0.629
6.300	26.25	1441.	20194.	40622.	36067.	26958.	2820.	1.000	0.652
6.400	28.02	1507.	20548.	41303.	36669.	27400.	2812.	1.000	0.674
6.500	29.87	1574.	20883.	41948.	37238.	27818.	2803.	1.000	0.698
6.600	31.80	1641.	21198.	42555.	37774.	28211.	2795.	1.000	0.721
6.700	33.81	1710.	21493.	43123.	38275.	28580.	2786.	1.000	0.745
6.800	35.90	1780.	21767.	43651.	38741.	28922.	2778.	1.000	0.769
6.900	38.08	1850.	22020.	44139.	39172.	29239.	2769.	1.000	0.794
7.000	40.34	1922.	22252.	44586.	39567.	29529.	2761.	1.000	0.819
7.100	42.69	1994.	22463.	44992.	39926.	29793.	2752.	1.000	0.844
7.191	44.89	2059.	22539.	45141.	40057.	29890.	2743.	1.000	0.864
LOCAL PRESSURE MAX DETECTED									
7.191	44.89	2059.	22539.	45141.	40057.	29890.	2743.	1.000	0.864
LOCAL PRESSURE MIN DETECTED									
7.200	45.13	2066.	22539.	45140.	4005[illegible]	29889.	2742.	1.000	0.866
LOCAL PRESSURE MAX DETECTED									
7.300	47.65	2139.	22465.	45001.	39934.	29800.	2731.	1.000	0.884
7.400	50.26	2211.	22298.	44680.	39651.	29593.	2720.	1.000	0.900
7.500	52.95	2282.	22058.	44221.	39246.	29296.	2708.	1.000	0.913
7.600	55.74	2353.	21759.	43649.	38742.	28926.	2695.	1.000	0.926
7.700	58.60	2422.	21413.	42986.	38156.	28497.	2682.	1.000	0.936
7.800	61.55	2491.	21028.	42247.	37504.	28019.	2669.	1.000	0.945
7.900	64.58	2558.	20611.	41447.	36798.	27501.	2655.	1.000	0.954
8.000	67.69	2623.	20166.	40597.	36048.	26951.	2641.	1.000	0.960
8.100	70.87	2687.	19706.	39710.	35265.	26376.	2627.	1.000	0.966
8.200	74.14	2750.	19234.	38805.	34467.	25790.	2613.	1.000	0.972
8.300	77.47	2811.	18759.	37893.	33662.	25200.	2599.	1.000	0.976
8.400	80.88	2871.	18283.	36979.	32856.	24608.	2585.	1.000	0.980
8.500	84.36	2929.	17808.	36067.	32051.	24018.	2571.	1.000	0.984
8.600	87.91	2986.	17337.	35161.	31251.	23430.	2557.	1.000	0.987
8.700	91.53	3041.	16869.	34263.	30458.	22849.	2542.	1.000	0.990
8.800	95.21	3094.	16407.	33375.	29675.	22274.	2528.	1.000	0.992
8.900	98.95	3146.	15952.	32501.	28903.	21707.	2514.	1.000	0.994
9.000	102.76	3197.	15505.	31641.	28144.	21150.	2500.	1.000	0.996
9.100	106.63	3246.	15065.	30796.	27398.	20603.	2486.	1.000	0.997
9.200	110.55	3294.	14635.	29969.	26668.	20066.	2472.	1.000	0.998
9.300	114.53	3341.	14215.	29160.	25954.	19542.	2458.	1.000	0.999
9.400	118.57	3386.	13804.	28369.	25256.	19029.	2444.	1.000	1.000
9.500	122.66	3429.	13403.	27598.	24575.	18529.	2430.	1.000	1.000
9.537	124.18	3445.	13257.	27317.	24327.	18347.	2425.	1.000	1.000
PROPELLANT 2 BURNED OUT									
9.600	126.79	3472.	13013.	26848.	23913.	18042.	2417.	1.000	1.000
9.700	130.99	3513.	12637.	26124.	23273.	17573.	2403.	1.000	1.000
9.800	135.23	3553.	12275.	25426.	22657.	17120.	2390.	1.000	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
9.900	139.51	3592.	11926.	24753.	22063.	16683.	2377.	1.000	1.000
10.000	143.85	3630.	11589.	24104.	21490.	16263.	2364.	1.000	1.000
10.100	148.23	3667.	11265.	23479.	20938.	15857.	2351.	1.000	1.000
10.200	152.65	3703.	10952.	22876.	20406.	15465.	2339.	1.000	1.000
10.300	157.11	3737.	10651.	22294.	19892.	15087.	2326.	1.000	1.000
10.400	161.62	3771.	10361.	21733.	19397.	14723.	2314.	1.000	1.000
10.500	166.16	3804.	10081.	21192.	18919.	14372.	2302.	1.000	1.000
10.600	170.75	3836.	9811.	20670.	18458.	14032.	2291.	1.000	1.000
10.700	175.37	3867.	9550.	20167.	18013.	13705.	2279.	1.000	1.000
10.800	180.03	3898.	9299.	19680.	17583.	13389.	2267.	1.000	1.000
10.900	184.72	3927.	9056.	19211.	17168.	13083.	2256.	1.000	1.000
11.000	189.45	3956.	8822.	18757.	16768.	12788.	2245.	1.000	1.000
11.100	194.22	3984.	8596.	18320.	16381.	12503.	2234.	1.000	1.000
11.200	199.02	4011.	8376.	17897.	16007.	12228.	2223.	1.000	1.000
11.300	203.85	4038.	8167.	17488.	15646.	11961.	2213.	1.000	1.000
11.400	208.71	4064.	7964.	17093.	15296.	11704.	2202.	1.000	1.000
11.500	213.60	4089.	7767.	16710.	14959.	11455.	2192.	1.000	1.000
11.600	218.52	4114.	7577.	16341.	14632.	11214.	2182.	1.000	1.000
11.700	223.47	4138.	7394.	15984.	14316.	10981.	2172.	1.000	1.000
11.800	228.45	4162.	7216.	15638.	14010.	10755.	2162.	1.000	1.000
11.900	233.46	4185.	7044.	15303.	13714.	10536.	2152.	1.000	1.000
12.000	238.50	4207.	6878.	14979.	13428.	10325.	2143.	1.000	1.000
12.100	243.56	4229.	6717.	14665.	13150.	10120.	2133.	1.000	1.000
12.200	248.64	4250.	6562.	14361.	12881.	9921.	2124.	1.000	1.000
12.300	253.76	4271.	6411.	14067.	12621.	9728.	2115.	1.000	1.000
12.400	258.90	4292.	6266.	13781.	12368.	9542.	2106.	1.000	1.000
12.500	264.06	4312.	6124.	13504.	12123.	9360.	2097.	1.000	1.000
12.600	269.24	4331.	5988.	13236.	11886.	9185.	2088.	1.000	1.000
12.700	274.45	4350.	5855.	12976.	11655.	9014.	2080.	1.000	1.000
12.800	279.68	4369.	5727.	12724.	11432.	8849.	2071.	1.000	1.000
12.900	284.94	4387.	5602.	12479.	11215.	8688.	2063.	1.000	1.000
13.000	290.21	4405.	5482.	12241.	11004.	8532.	2054.	1.000	1.000
13.100	295.51	4422.	5365.	12010.	10800.	8380.	2046.	1.000	1.000
13.200	300.83	4439.	5251.	11786.	10601.	8233.	2038.	1.000	1.000
13.300	306.16	4456.	5141.	11568.	10408.	8090.	2030.	1.000	1.000
13.400	311.52	4473.	5034.	11356.	10221.	7950.	2022.	1.000	1.000
13.500	316.90	4489.	4930.	11151.	10039.	7815.	2014.	1.000	1.000
13.600	322.29	4504.	4829.	10951.	9862.	7683.	2007.	1.000	1.000
13.700	327.71	4520.	4732.	10756.	9689.	7555.	1999.	1.000	1.000
13.800	333.14	4535.	4637.	10567.	9522.	7430.	1992.	1.000	1.000
13.900	338.59	4550.	4544.	10384.	9359.	7309.	1984.	1.000	1.000
14.000	344.06	4564.	4455.	10205.	9200.	7190.	1977.	1.000	1.000
14.100	349.54	4578.	4368.	10030.	9045.	7075.	1970.	1.000	1.000
14.200	355.05	4592.	4283.	9861.	8895.	6963.	1963.	1.000	1.000
14.300	360.57	4606.	4201.	9696.	8748.	6854.	1956.	1.000	1.000
14.400	366.10	4619.	4120.	9535.	8606.	6747.	1949.	1.000	1.000
14.500	371.65	4632.	4043.	9378.	8467.	6643.	1942.	1.000	1.000
14.600	377.22	4645.	3967.	9226.	8331.	6542.	1935.	1.000	1.000
14.700	382.80	4658.	3893.	9077.	8199.	6443.	1928.	1.000	1.000
14.800	388.40	4670.	3822.	8932.	8070.	6347.	1922.	1.000	1.000
14.900	394.01	4683.	3752.	8791.	7945.	6252.	1915.	1.000	1.000
15.000	399.64	4695.	3684.	8653.	7822.	6161.	1909.	1.000	1.000
15.100	405.28	4706.	3618.	8519.	7703.	6071.	1902.	1.000	1.000
15.200	410.93	4718.	3553.	8388.	7586.	5983.	1896.	1.000	1.000
15.300	416.60	4729.	3491.	8260.	7472.	5898.	1890.	1.000	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
15.400	422.28	4740.	3430.	8135.	7361.	5814.	1884.	1.000	1.000
15.500	427.97	4751.	3370.	8013.	7253.	5733.	1877.	1.000	1.000
15.600	433.68	4762.	3312.	7894.	7147.	5653.	1871.	1.000	1.000
15.700	439.40	4773.	3256.	7778.	7044.	5575.	1865.	1.000	1.000
15.800	445.14	4783.	3201.	7664.	6943.	5499.	1860.	1.000	1.000
15.900	450.88	4793.	3147.	7554.	6844.	5424.	1854.	1.000	1.000
16.000	456.64	4803.	3095.	7445.	6747.	5351.	1848.	1.000	1.000
16.100	462.41	4813.	3044.	7340.	6653.	5280.	1842.	1.000	1.000
16.200	468.19	4823.	2994.	7236.	6561.	5210.	1837.	1.000	1.000
16.300	473.98	4832.	2946.	7135.	6471.	5142.	1831.	1.000	1.000
16.400	479.79	4842.	2898.	7036.	6382.	5075.	1825.	1.000	1.000
16.500	485.60	4851.	2852.	6940.	6296.	5010.	1820.	1.000	1.000
16.600	491.43	4860.	2807.	6845.	6212.	4946.	1815.	1.000	1.000
16.700	497.27	4869.	2763.	6753.	6129.	4883.	1809.	1.000	1.000
16.800	503.12	4878.	2720.	6662.	6048.	4821.	1804.	1.000	1.000
16.900	508.98	4887.	2679.	6574.	5969.	4761.	1799.	1.000	1.000
17.000	514.85	4895.	2638.	6487.	5892.	4702.	1793.	1.000	1.000
17.100	520.72	4904.	2598.	6402.	5816.	4644.	1788.	1.000	1.000
17.200	526.61	4912.	2559.	6319.	5742.	4587.	1783.	1.000	1.000
17.300	532.51	4920.	2521.	6238.	5669.	4532.	1778.	1.000	1.000
17.400	538.42	4928.	2484.	6158.	5598.	4477.	1773.	1.000	1.000
17.500	544.34	4936.	2448.	6080.	5528.	4424.	1768.	1.000	1.000
17.600	550.27	4944.	2413.	6004.	5460.	4371.	1763.	1.000	1.000
17.700	556.21	4952.	2378.	5929.	5393.	4320.	1758.	1.000	1.000
17.800	562.15	4959.	2344.	5856.	5327.	4270.	1753.	1.000	1.000
17.900	568.11	4967.	2311.	5784.	5263.	4220.	1749.	1.000	1.000
17.940	570.50	4970.	2298.	5756.	5237.	4200.	1747.	1.000	1.000

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	7.191	17.940
TRAVEL (IN):	44.89	570.50
VELOCITY (FT/S)	2059.	4970.
ACCELFRATION (G):	22539.	2248.
BREECH PRESS (PSI):	45141.	5756.
MEAN PRESS (PSI):	40057.	5237.
BASE PRESS (PSI):	29890.	4200.
MEAN TEMP (K):	2743.	1747.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.864	1.000

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	979802624.	100.00
(1) INTERNAL GAS:	570262272.	58.20
(2) WORK AND LOSSES:	409540352.	41.80
(A) PROJECTILE KINETIC:	239312960.	24.42
(B) GAS KINETIC:	86697888.	8.85
(C) PROJECTILE ROTATIONAL:	120496.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	31748304.	3.24
(F) WORK DONE AGAINST AIR:	8145177.	0.83
(G) HEAT CONVECTED TO BORE:	43515312.	4.44
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	0.357
CHARGE WT/PROJECTILE WT:	1.087
PIEZOMETRIC EFFICIENCY:	0.223
EXPANSION RATIO:	6.442

Test Case 2

This case demonstrates how to include two successive, but independent, runs as a single input file. The input descriptions do not overlap because the program will reset all parameters after an $END card unless specifically told not to do so. The main propellant in the first subcase is divided into three layers: outer layer (2) is a deterred propellant with a low burning rate, middle layer (3) is a thin transition zone, and the inner layer (4) is a fast-burning propellant. The transition zone is used to avoid an abrupt change in burning rates. Though all surfaces (lateral, end, and perforation) are defined for layers 2 and 3, the core layer has its end and perforation parameters overridden by the lateral inputs. Gun chamber length is defined as 5 inches, and pressure gages are specified at the breech end (position at -5.0 inches with respect to the base of projectile) and at the projectile end (position 0.0 inches) of the chamber. The default equations for finding internal pressures are Lagrangian, but Pidduck-Kent is used in this case.

The second data set also uses the Pidduck-Kent gradient to solve for internal pressures. A prominent feature here is the form function 'GEN' instead of the standard '7PF' granulation. The data for the depth-burned versus surface array came from a similar run where DB-P and SRF(2) were printed as part of the trajectory information. (See input descriptions for $TDIS, $TRAJ, and $INFO decks.) Again, the igniter has been split into two parts with a small portion as $PRIM and the rest as the first $PROP deck. Blank lines and liberal indents allow easy readability, but are not necessary.

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$COMMENT
    IBHVG2 BENCHMARK TEST CASE 2

    TWO INDEPENDENT DATA SETS IN ONE IBHVG2 RUN

       FIRST SET : LATERALLY DETERRED PROPELLANT
                   (VERY THIN TRANSITION ZONE BETWEEN OUTER AND INNER
                    PROPELLANT TYPES, RESULTING IN THREE LAYERS)
                      1 - DETERRENT, .0007 THICK, LOW B/R EXPONENT
                      2 - TRANSITION ZONE, .0001 THICK, FROM LOW TO HI EXP
                      3 - CORE PROPELLANT, HI BURNING RATE

       SECOND SET : STANDARD 105MM CANNON
                    PIDDUCK-KENT INTERNAL PRESSURE GRADIENT EQUATION
                    USE GENERAL GRAIN FORM F'NCTION

$HEAT
      TSHL = 0.00450         CSHL = 1848       RSHL = 0.284
      TWAL = 293             HO   = 0.0648     HL   = 1

$GUN
      NAME='XM881 25MM APFSDS-T'  CHAM=5.86  GRVE=0.988 LAND=0.980
      G/L=1.  TRAV=74  TWST=25
      CLEN=5  NGAG=2  GLOC=-5,0

$PROJ
      NAME = 'APFSDS-T'   PRWT = 0.170

$RESI
      NPTS = 4               AIR  = 1
      TRAV =       0,   0.2,   1.0,   74
      PRES =     200,  2000,  400,  400

$INFO
      RUN  = '120MATCH-182M881  '   DELT = 5E-5        DELP = 5E-5
      GRAD = 2               POPT = 1,1,1,0,2   SOPT = 0
      EPS  = 0.002           COMP = 0
```

```
$RECO
     NAME = 'NONE'          RECO = 0          RCWT = 0

$PRIN
     NAME='B/KNO3'  CHWT=0.00022
     GAMA = 1.25    FORC = 212500
     COV  = 30      TEMP = 2000

$PROP
  NAME='M10 7P'   CHWT=0.2071   GRAN='7PF'
  RHO=0.06   GAMA=1.2385  FORC=330000
  COV=27.04  TEMP=3073    EROS=0
  NTBL=-1
  PR2P=100000   PR2E=100000   PR2L=100000
  PR3P=100000   PR3E=100000   PR3L=100000
  PR4L=100000
  CF2P=.00289   CF2E=0.00289  CF2L=0.00289
  EX2P=0.678    EX2E=0.678    EX2L=0.678
  CF3P=0.00289  CF3E=0.00289  CF3L=0.00289
  EX3P=0.678    EX3E=0.678    EX3L=0.678
  CF4L=0.004656 EX4L=0.7061
  DEPP=,0.0007,0.0008 DEPE=,0.0007,0.0008 DEPL=,0.0007,0.0008
  LEN=0.0972    DIAM=0.0928   PD=0.0058
  WI=0.0175     WO=0.0202
$END


$HEAT
  TSHL = 0.00450         CSHL = 1848       RSHL = 0.284
  TWAL = 293             HO   = 0.0648     HL   = 1

$GUN
  NAME = ' 105-MM GUN M68'    CHAM = 375        GRVE = 4.224
  LAND = 4.134           G/L  = 2.       TRAV = 187
  TWST = 99

$PROJ
  NAME = 'M456A2'    PRWT = 23.2

$RESI
  NPTS = 4               AIR  = 1
  TRAV =       0,     0.5,   8.0,   187
  PRES =     100,    2100,   500,   200

$INFO
  RUN = '105MATCH-I105'   DELT = 5E-5       DELP = 5E-5
  GRAD = 2               POPT = 1,1,1,0,2    SOPT = 0
  EPS  = 0.002           COMP = 0

$RECO
  NAME = 'NONE'          RECO = 0          RCWT = 0

$PRIN
  NAME = 'BENITE'        CHWT = 0.001
  GAMA = 1.25          FORC = 212500
  COV  = 30              TEMP = 2000

$PROP
  NAME = 'BENITE'        CHWT = 0.072    GRAN = 'CORD'
  RHO  = 0.06          GAMA = 1.25        FORC = 212500
  COV  = 30              TEMP = 2000        EROS = 0.00000
  ALPH = 0               BETA = 10          IGNC = 0
  LEN  = 10.           DIAM = 0.08

$PROP
  NAME = 'M30 7P'      CHWT = 11.9      GRAN='GEN'
  RHO  = 0.0607        GAMA = 1.241     FORC = 360000
  COV  = 29.11            TEMP = 3010        EROS = 0.0000000
  NTBL=0 ALPH=0.8  BETA=0.001320
       $  THE FOLLOWING PARAMETERS REPLACED BY DEPTH-BURNED/SURFACE ARRAY
       $   LEN  =0.63        DIAM = 0.3087       PD = 0.0245
       $   WEB=0.0588      GRAN = '7PF'
  NSUR=8
  DEPB=0.,    0.0106, 0.02925, 0.0300, 0.0330, 0.0351, 0.038, 0.040
  SURF=4756.,5517.,  6589.,   5067.,  2823.,  1900.,  1100., 710.

$END
```

Producing the following output:

```
 ERRTOL=   4.768372E-07

CARD   1 --> $COMMENT
CARD   2 -->      IBHVG2 BENCHMARK TEST CASE 2
CARD   3 -->
CARD   4 -->      TWO INDEPENDENT DATA SETS IN ONE IBHVG2 RUN
CARD   5 -->
CARD   6 -->         FIRST SET : LATERALLY DETERRED PROPELLANT
CARD   7 -->                     (VERY THIN TRANSITION ZONE BETWEEN OUTER AND INNER
CARD   8 -->                      PROPELLANT TYPES, RESULTING IN THREE LAYERS)
CARD   9 -->                        1 - DETERRENT, .0007 THICK, LOW B/R EXPONENT
CARD  10 -->                        2 - TRANSITION ZONE, .0001 THICK, FROM LOW TO HI EXP
CARD  11 -->                        3 - CORE PROPELLANT, HI BURNING RATE
CARD  12 -->
CARD  13 -->         SECOND SET : STANDARD 105MM CANNON
CARD  14 -->                      PIDDUCK-KENT INTERNAL PRESSURE GRADIENT EQUATION
CARD  15 -->                      USE GENERAL GRAIN FORM FUNCTION
CARD  16 -->
CARD  17 --> $HEAT
CARD  18 -->       TSHL = 0.00450         CSHL = 1848       RSHL = 0.284
CARD  19 -->       TWAL = 293            HO   = 0.0648     HL   = 1
CARD  20 -->
CARD  21 --> $GUN
CARD  22 -->       NAME='XM881 25MM APFSDS-T'  CHAM=5.86  GRVE=0.988 LAND=0.960
CARD  23 -->       G/L=1.  TRAV=74  TWST=25
CARD  24 -->       CLEN=5  NGAG=2  GLOC=-5,0
CARD  25 -->
CARD  26 --> $PROJ
CARD  27 -->       NAME = 'APFSDS-T'   PRWT = 0.170
CARD  28 -->
CARD  29 --> $RESI
CARD  30 -->       NPTS = 4                 AIR  = 1
CARD  31 -->       TRAV =      0,   0.2,   1.0,   74
CARD  32 -->       PRES =    200,  2000,  400,  400
CARD  33 -->
CARD  34 --> $INFO
CARD  35 -->       RUN  = '120MATCH-I82M881  '   DELT = 5E-5        DELP = 5E-5
CARD  36 -->       GRAD = 2                 POPT = 1,1,1,0,2    SOPT = 0
CARD  37 -->       EPS  = 0.002             COMP = 0
CARD  38 -->
CARD  39 --> $RECO
CARD  40 -->       NAME = 'NONE'            RECO = 0            RCWT = 0
CARD  41 -->
CARD  42 --> $PRIN
CARD  43 -->       NAME='B/KNO3'  CHWT=0.00022
CARD  44 -->       GAMA = 1.25    FORC = 212500
CARD  45 -->       COV  = 30      TEMP = 2000
CARD  46 -->
CARD  47 --> $PROP
CARD  48 -->     NAME='M10 7P'    CHWT=0.2071    GRAN='7PF'
CARD  49 -->     RHO=0.06   GAMA=1.2385  FORC=330000
CARD  50 -->     COV=27.04  TEMP=3073    EROS=0
CARD  51 -->     NTBL=-1
CARD  52 -->     PR2P=100000    PR2E=100000    PR2L=100000
CARD  53 -->     PR3P=100000    PR3E=100000    PR3L=100000
CARD  54 -->     PR4L=100000
CARD  55 -->     CF2P=.00289    CF2E=0.00289   CF2L=0.00289
```

```
CARD  56 -->   EX2P=0.678    EX2E=0.678    EX2L=0.678
CARD  57 -->   CF3P=0.00289  CF3E=0.00289  CF3L=0.00289
CARD  58 -->   EX3P=0.678    EX3E=0.678    EX3L=0.678
CARD  59 -->   CF4L=0.004656 EX4L=0.7061
CARD  60 -->   DEPP=,0.0007,0.0008 DEPE=,0.0007,0.0008 DEPL=,0.0007,0.0008
CARD  61 -->   LEN=0.0972    DIAM=0.0928   PD=0.0058
CARD  62 -->   WI=0.0175     WO=0.0202
CARD  63 --> $END
```

```
------------
- GUN TUBE -
------------

 TYPE: XM881 25MM APFSDS-T                      CHAMBER VOLUME (IN3):              5.86    TRAVEL (IN):                    74.00
 GROOVE DIAMETER (IN):            0.988         LAND DIAMETER (IN):                0.980   GROOVE/LAND RATIO (-):          1.000
 TWIST (CALS/TURN):                25.0         BORE AREA (IN2):                   0.7605  HEAT-LOSS OPTION:                   1
 SHELL THICKNESS (IN):         0.004500         SHELL CP (IN-LB/LB-K):             1848.0  SHELL DENSITY (LB/IN3):        0.2840
 INITIAL SHELL TEMP (K):           293.         AIR HO (IN-LB/IN2-S-K):           0.06480

 NO. GAGES:                           2         CHAMBER LENGTH (IN):               5.00

  I      LOCATION (IN)                           I      LOCATION (IN)                        I      LOCATION (IN)

  1          -5.00                               2          0.00

--------------
- PROJECTILE -
--------------

 TYPE: APFSDS-T                                 TOTAL WEIGHT (LB):                 0.170   WEIGHT PREDICTOR OPTION:            0

--------------
- RESISTANCE -
--------------

 AIR RESISTANCE OPTION:               1         WALL HEATING FRACTION:             0.000   FRICTION TABLE LENGTH:              4

  I   TRAVEL (IN)    PRESSURE (PSI)              I   TRAVEL (IN)    PRESSURE (PSI)           I   TRAVEL (IN)    PRESSURE (PSI)

  1      0.00             200.                   3      1.00            400.                 4     74.00            400.
  2      0.20            2000.

-----------
- GENERAL -
-----------

 MAX TIME STEP (S):            0.000050         PRINT STEP (S):                 0.000050   MAX RELATIVE ERROR (-):       0.00200
 PRINT OPTIONS:             1 1 1 0 2 1         STORE OPTION:                          0   CONSTANT-PRESSURE OPTION:           0
 GRADIENT MODEL: PIDDUCK-KENT

----------
- RECOIL -
----------

 RECOIL OPTION:                       0         TYPE: NONE                                 RECOILING WEIGHT (LB):             0.

----------
- PRIMER -
----------

 TYPE: B/KNO3                                   GAMMA (-):                        1.2500   FORCE (FT-LB/LB):             212500.
 COVOLUME (IN3/LB):              30.000         FLAME TEMP (K):                   2000.0   WEIGHT (LB):                 0.000220
```

- CHARGE 1 -

TYPE: M10 7P		GRAINS:	5397.8 7PF	WEIGHT (LB):	0.2071
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.09720	GRAIN DIAMETER (IN):	0.09280	PERF DIAMETER (IN):	0.00580
INNER WEB (IN):	0.01750	OUTER WEB (IN):	0.02020		

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	0.00000	0.00070	0.00080
ADJACENT LAYER WT %:	------	1.510	0.240	93.161
DENSITY (LB/IN3):	------	0.06000	0.06000	0.06000
GAMMA (-):	------	1.2385	1.2385	1.2385
FORCE (FT-LB/LB):	------	330000.	330000.	330000.
COVOLUME (IN3/LB):	------	27.040	27.040	27.040
FLAME TEMP (K):	------	3073.0	3073.0	3073.0
MEAN PRESSURES (PSI):	------	100000.0	100000.0	100000.0
BURNING RATE EXPS:	------	0.6780	0.6780	0.7061
BURNING RATE COEFFS:	------	0.0028900	0.0028900	0.0046560

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	0.00000	0.00070	0.00080
ADJACENT LAYER WT %:	------	1.408	0.196	93.161
DENSITY (LB/IN3):	------	0.06000	0.06000	0.06000
GAMMA (-):	------	1.2385	1.2385	1.2385
FORCE (FT-LB/LB):	------	330000.	330000.	330000.
COVOLUME (IN3/LB):	------	27.040	27.040	27.040
FLAME TEMP (K):	------	3073.0	3073.0	3073.0
MEAN PRESSURES (PSI):	------	100000.0	100000.0	100000.0
BURNING RATE EXPS:	------	0.6780	0.6780	0.7061
BURNING RATE COEFFS:	------	0.0028900	0.0028900	0.0046560

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	0.00000	0.00070	0.00080
ADJACENT LAYER WT %:	------	3.057	0.429	93.161
DENSITY (LB/IN3):	------	0.06000	0.06000	0.06000
GAMMA (-):	------	1.2385	1.2385	1.2385
FORCE (FT-LB/LB):	------	330000.	330000.	330000.
COVOLUME (IN3/LB):	------	27.040	27.040	27.040
FLAME TEMP (K):	------	3073.0	3073.0	3073.0
MEAN PRESSURES (PSI):	------	100000.0	100000.0	100000.0
BURNING RATE EXPS:	------	0.6780	0.6780	0.7061
BURNING RATE COEFFS:	------	0.0028900	0.0028900	0.0046560

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1
0.000	0.00	0.	0.	234.	234.	234.	2000.	0.000
0.050	0.00	0.	570.	516.	449.	328.	2411.	0.001
0.100	0.00	2.	1586.	882.	768.	561.	2651.	0.002
0.150	0.00	6.	2950.	1393.	1212.	885.	2793.	0.003
0.200	0.01	12.	4677.	2073.	1803.	1317.	2878.	0.005
0.250	0.02	21.	6765.	2944.	2561.	1871.	2932.	0.007
0.300	0.03	34.	9183.	4024.	3500.	2557.	2965.	0.010
0.350	0.06	51.	11867.	5324.	4631.	3383.	2985.	0.013
0.400	0.10	72.	14714.	6843.	5953.	4349.	2995.	0.017
0.450	0.15	98.	17574.	8569.	7454.	5445.	2999.	0.022
0.500	0.21	129.	20933.	10472.	9109.	6654.	2996.	0.027
0.550	0.30	168.	27484.	12499.	10873.	7943.	2988.	0.034
0.600	0.42	217.	34389.	14569.	12673.	9258.	2974.	0.041
0.650	0.57	278.	41401.	16571.	14415.	10530.	2954.	0.049
0.700	0.75	351.	48241.	18388.	15995.	11685.	2927.	0.057
0.714	0.81	372.	50010.	18825.	16375.	11963.	2918.	0.060
LAYER TRANSITION 2 TO 3 ON PERF SURFACE OF PROPELLANT 1								
LAYER TRANSITION 2 TO 3 ON END SURFACE OF PROPELLANT 1								
LAYER TRANSITION 2 TO 3 ON LAT SURFACE OF PROPELLANT 1								
SHOT-START PRESSURE ACHIEVED								
0.745	0.96	426.	56718.	20715.	18019.	13163.	2904.	0.068
LAYER TRANSITION 3 TO 4 ON PERF SURFACE OF PROPELLANT 1								
LAYER TRANSITION 3 TO 4 ON END SURFACE OF PROPELLANT 1								
LAYER TRANSITION 3 TO 4 ON LAT SURFACE OF PROPELLANT 1								
0.750	0.99	435.	58346.	21208.	18448.	13477.	2903.	0.070
0.800	1.28	540.	72675.	26216.	22804.	16659.	2885.	0.093
0.850	1.64	668.	86257.	31000.	26966.	19699.	2857.	0.119
0.900	2.09	817.	98072.	35165.	30589.	22346.	2821.	0.148
0.950	2.62	983.	107234.	38399.	33402.	24401.	2777.	0.180
1.000	3.27	1161.	113276.	40537.	35262.	25760.	2729.	0.213
1.050	4.02	1346.	116204.	41582.	36171.	26424.	2678.	0.248
1.079	4.51	1456.	116611.	41735.	36304.	26521.	2647.	0.269
LOCAL PRESSURE MAX DETECTED								
1.100	4.88	1533.	116389.	41665.	36243.	26476.	2626.	0.284
1.150	5.86	1719.	114406.	40986.	35653.	26045.	2573.	0.319
1.200	6.95	1901.	110871.	39763.	34588.	25268.	2522.	0.355
1.250	8.14	2076.	106336.	38189.	33220.	24268.	2473.	0.389
1.300	9.44	2243.	101247.	36421.	31682.	23144.	2426.	0.423
1.350	10.83	2402.	95931.	34574.	30075.	21970.	2382.	0.456
1.400	12.32	2552.	90614.	32726.	28467.	20796.	2340.	0.488
1.450	13.89	2694.	85441.	30929.	26904.	19654.	2301.	0.518
1.500	15.55	2827.	80500.	29213.	25411.	18564.	2264.	0.548
1.550	17.28	2953.	75837.	27595.	24004.	17535.	2229.	0.576
1.600	19.09	3072.	71472.	26081.	22687.	16573.	2176.	0.604
1.650	20.97	3183.	67406.	24672.	21461.	15678.	2165.	0.630
1.700	22.91	3289.	63631.	23365.	20324.	14847.	2136.	0.655
1.750	24.91	3388.	60133.	22154.	19271.	14078.	2108.	0.680
1.800	26.97	3483.	56892.	21033.	18296.	13366.	2082.	0.704
1.850	29.09	3572.	53891.	19997.	17394.	12707.	2057.	0.726
1.900	31.26	3656.	51110.	19037.	16559.	12097.	2033.	0.749
1.950	33.48	3736.	48531.	18147.	15786.	11532.	2011.	0.770
2.000	35.74	3813.	46136.	17322.	15068.	11008.	1989.	0.791
2.050	38.05	3885.	43910.	16556.	14402.	10521.	1968.	0.811
2.100	40.40	3954.	41744.	15811.	13753.	10047.	1946.	0.829
2.150	42.79	4019.	39598.	15072.	13110.	9577.	1924.	0.845

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1
2.200	45.22	4082.	37540.	14362.	12493.	9127.	1901.	0.860
2.250	47.69	4140.	35585.	13689.	11908.	8699.	1878.	0.873
2.300	50.19	4196.	33737.	13054.	11355.	8295.	1855.	0.886
2.350	52.73	4249.	31996.	12454.	10834.	7914.	1833.	0.897
2.400	55.29	4299.	30358.	11891.	10344.	7556.	1812.	0.908
2.450	57.88	4347.	28817.	11361.	9883.	7220.	1790.	0.918
2.500	60.51	4392.	27312.	10844.	9433.	6891.	1768.	0.927
2.550	63.15	4435.	25853.	10342.	8996.	6572.	1745.	0.934
2.600	65.83	4475.	24462.	9864.	8580.	6268.	1723.	0.940
2.650	68.52	4514.	23144.	9410.	8186.	5980.	1700.	0.946
2.700	71.24	4550.	21903.	8984.	7815.	5709.	1678.	0.951
2.750	73.98	4584.	20735.	8582.	7465.	5454.	1656.	0.955
2.750	74.00	4584.	20729.	8580.	7464.	5452.	1656.	0.955

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	1.079	2.750
TRAVEL (IN):	4.51	74.00
VELOCITY (FT/S)	1456.	4584.
ACCELERATION (G):	116611.	20729.
BREECH PRESS (PSI):	41735.	8580.
MEAN PRESS (PSI):	36304.	7464.
BASE PRESS (PSI):	26521.	5452.
MEAN TEMP (K):	2647.	1656.
Z CHARGE 1 (-):	0.269	0.955

GAGE	AT (IN) WRT SOM	PMAX (PSI)
1	-5.00	41735.
2	0.00	35559.

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	3286882.	100.00
(1) INTERNAL GAS:	1771932.	53.91
(2) WORK AND LOSSES:	1514950.	46.09
(A) PROJECTILE KINETIC:	665761.	20.26
(B) GAS KINETIC:	245588.	7.47
(C) PROJECTILE ROTATIONAL:	5257.	0.16
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	23103.	0.70
(F) WORK DONE AGAINST AIR:	15303.	0.47
(G) HEAT CONVECTED TO BORE:	559938.	17.04
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	0.979
CHARGE WT/PROJECTILE WT:	1.220
PIEZOMETRIC EFFICIENCY:	0.283
EXPANSION RATIO:	10.603

```
CARD  64 -->
CARD  65 -->
CARD  66 --> $HEAT
CARD  67 -->  TSHL = 0.00450        CSHL = 1848        RSHL = 0.284
CARD  68 -->  TWAL = 293           HO    = 0.0648      HL    = 1
CARD  69 -->
CARD  70 --> $GUN
CARD  71 -->  NAME = ' 105-MM GUN M68'    CHAM = 375        GRVE = 4.224
CARD  72 -->  LAND = 4.134          G/L  = 2.       TRAV = 187
CARD  73 -->  TWST = 99
CARD  74 -->
CARD  75 --> $PROJ
CARD  76 -->  NAME = 'M456A2'   PRWT = 23.2
CARD  77 -->
CARD  78 --> $RESI
CARD  79 -->  NPTS = 4              AIR  = 1
CARD  80 -->  TRAV =       0,     0.5,  8.0,  187
CARD  81 -->  PRES =     100,    2100,  500,  200
CARD  82 -->
CARD  83 --> $INFO
CARD  84 -->  RUN = '105MATCH-1105'   DELT = 5E-5       DELP = 5E-5
CARD  85 -->  GRAD = 2              POPT = 1,1,1,0,2    SOPT = 0
CARD  86 -->  EPS  = 0.002          COMP = 0
CARD  87 -->
CARD  88 --> $RECO
CARD  89 -->  NAME = 'NONE'         RECO = 0          RCWT = 0
CARD  90 -->
CARD  91 --> $PRIM
CARD  92 -->  NAME = 'BENITE'       CHWT = 0.001
CARD  93 -->  GAMA = 1.25         FORC = 212500
CARD  94 -->  COV  = 30             TEMP = 2000
CARD  95 -->
CARD  96 --> $PROP
CARD  97 -->  NAME = 'BENITE'       CHWT = 0.072    GRAN = 'CORD'
CARD  98 -->  RHO  = 0.06          GAMA = 1.25       FORC = 212500
CARD  99 -->  COV  = 30             TEMP = 2000       EROS = 0.00000
CARD 100 -->  ALPH = 0              BETA = 10         IGNC = 0
CARD 101 -->  LEN  = 10.          DIAM = 0.08
CARD 102 -->
CARD 103 --> $PROP
CARD 104 -->  NAME = 'M30 7P'     CHWT = 11.9      GRAN='GEN'
CARD 105 -->  RHO  = 0.0607       GAMA = 1.241     FORC = 360000
CARD 106 -->  COV  = 29.11          TEMP = 3010       EROS = 0.0000000
CARD 107 -->  NTBL=0 ALPH=0.8  BETA=0.001320
CARD 108 -->        $  THE FOLLOWING PARAMETERS REPLACED BY DEPTH-BURNED/SURFACE ARRAY
CARD 109 -->        $   LEN  =0.63        DIAM = 0.3087       PD = 0.0245
CARD 110 -->        $   WEB=0.0588      GRAN = '7PF'
CARD 111 -->  NSUR=8
CARD 112 -->  DEPB=0.,    0.0106, 0.02925, 0.0300, 0.0330, 0.0351, 0.038, 0.040
CARD 113 -->  SURF=4756.,5517.,  6589.,   5067.,  2823.,   1900.,  1100., 710.
CARD 114 -->
CARD 115 --> $END
```

```
------------
- GUN TUBE -
------------

 TYPE: 105-MM GUN M68                   CHAMBER VOLUME (IN3)          375.00    TRAVEL (IN):                 187.00
 GROOVE DIAMETER (IN):        4.224     LAND DIAMETER (IN):            4.134    GROOVE/LAND RATIO (-):        2.000
 TWIST (CALS/TURN):            99.0     BORE AREA (IN2):             13.8163    HEAT-LOSS OPTION:                 1
 SHELL THICKNESS (IN):     0.004500     SHELL CP (IN-LB/LB-K):        1848.0    SHELL DENSITY (LB/IN3):      0.2840
 INITIAL SHELL TEMP (K):       293.     AIR HO (IN-LB/IN2-S-K):      0.06480

--------------
- PROJECTILE -
--------------

 TYPE: M456A2                           TOTAL WEIGHT (LB):            23.200    WEIGHT PREDICTOR OPTION:          0

--------------
- RESISTANCE -
--------------

 AIR RESISTANCE OPTION:           1     WALL HEATING FRACTION:         0.000    FRICTION TABLE LENGTH:            4

  I   TRAVEL (IN)    PRESSURE (PSI)      I   TRAVEL (IN)   PRESSURE (PSI)      I   TRAVEL (IN)   PRESSURE (PSI)

  1      0.00            100.            3       8.00          500.            4     187.00          200.
  2      0.50           2100.

-----------
- GENERAL -
-----------

 MAX TIME STEP (S):        0.000050     PRINT STEP (S):             0.000050    MAX RELATIVE ERROR (-):     0.00200
 PRINT OPTIONS:         1 1 1 0 2 1     STORE OPTION:                      0    CONSTANT-PRESSURE OPTION:         0
 GRADIENT MODEL: PIDDUCK-KENT

----------
- RECOIL -
----------

 RECOIL OPTION:                   0     TYPE: NONE                              RECOILING WEIGHT (LB):           0.

----------
- PRIMER -
----------

 TYPE: BENITE                           GAMMA (-):                    1.2500    FORCE (FT-LB/LB):           212500.
 COVOLUME (IN3/LB):          30.000     FLAME TEMP (K):               2000.0    WEIGHT (LB):               0.001000
```

- CHARGE 1 -

TYPE: BENITE		GRAINS:	23.873	CORD	WEIGHT (LB):	0.0720
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	10.00000	GRAIN DIAMETER (IN):		0.08000		

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06000	------	------	------	0.06000
GAMMA (-):	------	------	------	1.2500	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	212500.	------	------	------	212500.
COVOLUME (IN3/LB):	------	------	------	30.000	------	------	------	30.000
FLAME TEMP (K):	------	------	------	2000.0	------	------	------	2000.0
BURNING RATE EXPS:	------	------	------	0.0000	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	10.0000000	------	------	------	10.0000000

- CHARGE 2 -

TYPE: M30 7P		GRAINS:	1.0000	GEN	WEIGHT (LB):	11.9000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S):	0.00000E+00

I	DEPTH (IN)	SURFACE (IN2)	I	DEPTH (IN)	SURFACE (IN2)	I	DEPTH (IN)	SURFACE (IN2)
1	0.00000	4756.0	4	0.03000	5067.0	7	0.03800	1100.0
2	0.01060	5517.0	5	0.03300	2823.0	8	0.04000	710.0
3	0.02925	6589.0	6	0.03510	1900.0			

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06070
GAMMA (-):	------	------	------	1.2410
FORCE (FT-LB/LB):	------	------	------	360000.
COVOLUME (IN3/LB):	------	------	------	29.110
FLAME TEMP (K):	------	------	------	3010.0
BURNING RATE EXPS:	------	------	------	0.8000
BURNING RATE COEFFS:	------	------	------	0.0013200

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
0.000	0.00	0.	0.	14.	14.	14.	2000.	0.000	0.000
0.050	0.00	0.	0.	47.	47.	47.	2109.	0.025	0.000
0.100	0.00	0.	0.	86.	86.	86.	2177.	0.050	0.000
0.116	0.00	0.	0.	100.	100.	100.	2197.	0.058	0.000
SHOT-START PRESSURE ACHIEVED									
0.150	0.00	0.	7.	141.	131.	112.	2235.	0.074	0.000
0.200	0.00	0.	34.	196.	182.	157.	2286.	0.098	0.000
0.250	0.00	0.	63.	258.	241.	207.	2332.	0.122	0.000
0.300	0.00	0.	97.	329.	306.	263.	2375.	0.145	0.000
0.350	0.00	0.	134.	408.	380.	326.	2415.	0.168	0.001
0.400	0.00	1.	175.	496.	462.	397.	2452.	0.191	0.001
0.450	0.00	1.	221.	594.	553.	475.	2486.	0.213	0.001
0.500	0.00	1.	271.	703.	655.	562.	2518.	0.235	0.001
0.550	0.00	2.	326.	823.	766.	658.	2548.	0.257	0.002
0.600	0.00	2.	386.	955.	890.	764.	2576.	0.278	0.002
0.650	0.01	3.	451.	1101.	1025.	880.	2602.	0.300	0.002
0.700	0.01	4.	522.	1260.	1173.	1007.	2627.	0.320	0.003
0.750	0.01	5.	598.	1434.	1335.	1147.	2649.	0.341	0.003
0.800	0.01	6.	681.	1624.	1512.	1299.	2671.	0.361	0.004
0.850	0.02	7.	771.	1830.	1705.	1464.	2691.	0.381	0.004
0.900	0.02	8.	867.	2055.	1914.	1644.	2709.	0.400	0.005
0.950	0.03	10.	970.	2299.	2141.	1839.	2727.	0.420	0.006
1.000	0.03	11.	1080.	2563.	2387.	2050.	2743.	0.439	0.007
1.050	0.04	13.	1199.	2848.	2652.	2278.	2758.	0.457	0.007
1.100	0.05	15.	1325.	3157.	2939.	2525.	2772.	0.476	0.008
1.150	0.06	18.	1460.	3489.	3249.	2790.	2786.	0.494	0.009
1.200	0.07	20.	1603.	3846.	3581.	3076.	2798.	0.511	0.010
1.250	0.08	23.	1755.	4230.	3939.	3383.	2809.	0.529	0.012
1.300	0.10	26.	1917.	4642.	4322.	3712.	2820.	0.546	0.013
1.350	0.11	29.	2088.	5083.	4733.	4065.	2830.	0.562	0.014
1.400	0.13	32.	2269.	5555.	5173.	4443.	2839.	0.579	0.016
1.450	0.15	36.	2460.	6059.	5642.	4846.	2847.	0.595	0.017
1.500	0.18	40.	2662.	6597.	6143.	5276.	2855.	0.611	0.019
1.550	0.20	45.	2874.	7170.	6676.	5734.	2862.	0.626	0.021
1.600	0.23	50.	3097.	7779.	7244.	6222.	2869.	0.641	0.023
1.650	0.26	55.	3330.	8426.	7847.	6739.	2875.	0.656	0.025
1.700	0.30	60.	3575.	9113.	8486.	7288.	2880.	0.670	0.027
1.750	0.33	66.	3831.	9840.	9163.	7870.	2885.	0.685	0.029
1.800	0.38	73.	4098.	10609.	9879.	8485.	2890.	0.699	0.032
1.850	0.42	79.	4375.	11420.	10635.	9134.	2894.	0.712	0.034
1.900	0.47	87.	4665.	12276.	11432.	9818.	2897.	0.725	0.037
1.950	0.53	95.	5028.	13177.	12271.	10539.	2900.	0.738	0.040
2.000	0.58	103.	5486.	14124.	13152.	11296.	2902.	0.751	0.043
2.050	0.65	112.	5967.	15117.	14077.	12090.	2904.	0.763	0.047
2.100	0.72	122.	6471.	16156.	15044.	12921.	2906.	0.775	0.050
2.150	0.80	133.	6997.	17241.	16055.	13789.	2907.	0.787	0.054
2.200	0.88	145.	7547.	18373.	17108.	14694.	2907.	0.798	0.058
2.250	0.97	157.	8118.	19549.	18204.	15635.	2908.	0.809	0.062
2.300	1.07	171.	8712.	20769.	19340.	16611.	2907.	0.820	0.066
2.350	1.18	185.	9326.	22031.	20515.	17620.	2906.	0.831	0.071
2.400	1.29	201.	9961.	23333.	21728.	18661.	2905.	0.841	0.076
2.450	1.42	217.	10615.	24673.	22975.	19733.	2903.	0.851	0.081
2.500	1.55	235.	11286.	26046.	24254.	20832.	2901.	0.860	0.086
2.550	1.70	254.	11973.	27451.	25562.	21955.	2898.	0.869	0.092
2.600	1.86	274.	12674.	28881.	26894.	23099.	2894.	0.878	0.097

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
2.650	2.03	295.	13387.	30333.	28246.	24260.	2891.	0.887	0.103
2.700	2.21	317.	14110.	31802.	29614.	25435.	2886.	0.895	0.110
2.750	2.41	340.	14839.	33281.	30991.	26618.	2881.	0.903	0.116
2.800	2.62	365.	15572.	34764.	32372.	27804.	2876.	0.911	0.123
2.850	2.85	390.	16306.	36245.	33751.	28988.	2870.	0.918	0.130
2.900	3.09	417.	17037.	37717.	35122.	30165.	2864.	0.925	0.138
2.950	3.35	445.	17763.	39172.	36477.	31329.	2857.	0.931	0.145
3.000	3.62	474.	18479.	40604.	37810.	32474.	2850.	0.938	0.153
3.050	3.92	505.	19183.	42004.	39114.	33595.	2842.	0.944	0.161
3.100	4.23	536.	19871.	43366.	40383.	34684.	2834.	0.950	0.170
3.150	4.56	569.	20539.	44683.	41609.	35737.	2825.	0.955	0.178
3.200	4.91	602.	21186.	45947.	42786.	36748.	2816.	0.960	0.187
3.250	5.28	637.	21806.	47153.	43909.	37712.	2807.	0.965	0.196
3.300	5.67	672.	22399.	48294.	44971.	38625.	2797.	0.970	0.206
3.350	6.09	709.	22961.	49364.	45968.	39481.	2787.	0.974	0.215
3.400	6.53	746.	23490.	50360.	46395.	40278.	2776.	0.978	0.225
3.450	6.98	784.	23984.	51277.	47749.	41011.	2766.	0.981	0.235
3.500	7.47	823.	24442.	52113.	48527.	41679.	2755.	0.984	0.245
3.550	7.97	863.	24863.	52863.	49226.	42280.	2743.	0.987	0.256
3.600	8.50	903.	25183.	53528.	49846.	42811.	2732.	0.990	0.266
3.650	9.06	944.	25458.	54107.	50385.	43274.	2720.	0.992	0.277
3.700	9.64	985.	25692.	54599.	50842.	43668.	2709.	0.994	0.288
3.750	10.24	1027.	25884.	55003.	51219.	43991.	2697.	0.996	0.299
3.800	10.87	1069.	26035.	55321.	51515.	44246.	2685.	0.998	0.310
3.850	11.52	1111.	26146.	55556.	51734.	44433.	2673.	0.999	0.321
3.900	12.20	1153.	26219.	55711.	51878.	44557.	2661.	0.999	0.332
3.950	12.91	1195.	26256.	55789.	51950.	44619.	2649.	1.000	0.343
4.000	13.64	1237.	26257.	55793.	51954.	44623.	2637.	1.000	0.354
PROPELLANT 1 BURNED OUT									
4.050	14.39	1280.	26226.	55729.	51894.	44571.	2625.	1.000	0.366
LOCAL PRESSURE MAX DETECTED									
4.100	15.17	1322.	26164.	55599.	51776.	44468.	2613.	1.000	0.377
4.150	15.98	1364.	26073.	55410.	51598.	44316.	2601.	1.000	0.388
4.200	16.81	1406.	25956.	55165.	51370.	44121.	2590.	1.000	0.400
4.250	17.66	1448.	25814.	54869.	51094.	43884.	2578.	1.000	0.411
4.300	18.54	1489.	25651.	54527.	50775.	43610.	2566.	1.000	0.423
4.350	19.45	1530.	25467.	54142.	50417.	43302.	2555.	1.000	0.434
4.400	20.38	1571.	25265.	53719.	50023.	42964.	2544.	1.000	0.445
4.450	21.34	1611.	25047.	53263.	49598.	42599.	2533.	1.000	0.457
4.500	22.31	1652.	24815.	52776.	49145.	42210.	2522.	1.000	0.468
4.550	23.32	1691.	24570.	52263.	48668.	41800.	2511.	1.000	0.479
4.600	24.34	1731.	24314.	51728.	48169.	41371.	2501.	1.000	0.490
4.650	25.39	1770.	24049.	51173.	47652.	40928.	2490.	1.000	0.501
4.700	26.47	1808.	23777.	50601.	47120.	40470.	2480.	1.000	0.512
4.750	27.56	1846.	23497.	50016.	46575.	40003.	2470.	1.000	0.523
4.800	28.68	1884.	23213.	49420.	46020.	39526.	2460.	1.000	0.534
4.850	29.82	1921.	22924.	48816.	45457.	39042.	2451.	1.000	0.545
4.900	30.99	1958.	22633.	48204.	44888.	38553.	2441.	1.000	0.556
4.950	32.17	1994.	22339.	47589.	44315.	38061.	2432.	1.000	0.567
5.000	33.38	2030.	22044.	46971.	43739.	37567.	2423.	1.000	0.577
5.050	34.61	2065.	21749.	46351.	43162.	37071.	2414.	1.000	0.588
5.100	35.86	2100.	21453.	45732.	42586.	36576.	2405.	1.000	0.598
5.150	37.13	2134.	21159.	45115.	42011.	36082.	2396.	1.000	0.609
5.200	38.42	2168.	20866.	44500.	41439.	35591.	2388.	1.000	0.619
5.250	39.73	2201.	20575.	43890.	40870.	35103.	2380.	1.000	0.629

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
5.300	41.06	2234.	20286.	43284.	40306.	34618.	2372.	1.000	0.639
5.350	42.41	2266.	19999.	42683.	39747.	34138.	2364.	1.000	0.649
5.400	43.78	2298.	19716.	42089.	39193.	33662.	2356.	1.000	0.659
5.450	45.17	2330.	19436.	41501.	38646.	33192.	2348.	1.000	0.669
5.500	46.57	2361.	19159.	40921.	38106.	32728.	2341.	1.000	0.679
5.550	48.00	2392.	18886.	40348.	37572.	32270.	2333.	1.000	0.689
5.600	49.44	2422.	18617.	39784.	37047.	31819.	2326.	1.000	0.698
5.650	50.91	2451.	18352.	39228.	36529.	31374.	2319.	1.000	0.708
5.700	52.39	2481.	18091.	38680.	36019.	30936.	2312.	1.000	0.718
5.750	53.88	2510.	17834.	38141.	35517.	30505.	2305.	1.000	0.727
5.800	55.40	2538.	17581.	37611.	35023.	30081.	2299.	1.000	0.736
5.850	56.93	2566.	17333.	37090.	34538.	29664.	2292.	1.000	0.746
5.900	58.48	2594.	17089.	36578.	34061.	29255.	2286.	1.000	0.755
5.950	60.04	2621.	16849.	36075.	33593.	28852.	2280.	1.000	0.764
6.000	61.62	2648.	16614.	35581.	33133.	28457.	2273.	1.000	0.773
6.050	63.22	2675.	16383.	35096.	32682.	28070.	2267.	1.000	0.782
6.100	64.83	2701.	16156.	34621.	32239.	27689.	2261.	1.000	0.791
6.150	66.46	2727.	15934.	34154.	31804.	27316.	2256.	1.000	0.799
6.200	68.11	2752.	15716.	33696.	31377.	26949.	2250.	1.000	0.808
6.250	69.76	2778.	15502.	33247.	30959.	26590.	2244.	1.000	0.817
6.300	71.44	2802.	15292.	32806.	30549.	26238.	2239.	1.000	0.825
6.350	73.13	2827.	15087.	32374.	30147.	25893.	2233.	1.000	0.834
6.400	74.83	2851.	14885.	31951.	29752.	25554.	2228.	1.000	0.842
6.450	76.55	2875.	14688.	31536.	29366.	25222.	2223.	1.000	0.851
6.500	78.28	2898.	14491.	31122.	28981.	24891.	2217.	1.000	0.859
6.550	80.03	2921.	14283.	30686.	28574.	24542.	2212.	1.000	0.866
6.600	81.79	2944.	14065.	30227.	28148.	24175.	2205.	1.000	0.873
6.650	83.56	2967.	13839.	29752.	27705.	23795.	2199.	1.000	0.879
6.700	85.35	2989.	13613.	29276.	27262.	23415.	2192.	1.000	0.885
6.750	87.15	3010.	13387.	28803.	26821.	23036.	2185.	1.000	0.891
6.800	88.96	3032.	13163.	28331.	26382.	22659.	2179.	1.000	0.896
6.850	90.78	3053.	12940.	27863.	25946.	22284.	2172.	1.000	0.901
6.900	92.62	3074.	12719.	27398.	25513.	21913.	2165.	1.000	0.906
6.950	94.47	3094.	12500.	26937.	25084.	21544.	2158.	1.000	0.910
7.000	96.33	3114.	12283.	26481.	24659.	21179.	2151.	1.000	0.914
7.050	98.21	3133.	12069.	26029.	24239.	20818.	2144.	1.000	0.918
7.100	100.09	3153.	11857.	25583.	23823.	20461.	2136.	1.000	0.922
7.150	101.99	3172.	11647.	25142.	23412.	20108.	2129.	1.000	0.926
7.200	103.90	3190.	11440.	24706.	23006.	19760.	2122.	1.000	0.929
7.250	105.82	3208.	11236.	24277.	22606.	19416.	2115.	1.000	0.932
7.300	107.75	3226.	11035.	23853.	22212.	19077.	2108.	1.000	0.935
7.350	109.69	3244.	10837.	23435.	21824.	18744.	2100.	1.000	0.938
7.400	111.64	3261.	10643.	23028.	21443.	18417.	2093.	1.000	0.941
7.450	113.60	3278.	10453.	22628.	21071.	18097.	2086.	1.000	0.944
7.500	115.58	3295.	10267.	22236.	20706.	17784.	2079.	1.000	0.946
7.550	117.56	3311.	10085.	21852.	20349.	17477.	2072.	1.000	0.948
7.600	119.55	3327.	9907.	21476.	19999.	17177.	2065.	1.000	0.951
7.650	121.55	3343.	9733.	21108.	19656.	16882.	2057.	1.000	0.953
7.700	123.56	3359.	9562.	20748.	19321.	16594.	2050.	1.000	0.955
7.750	125.58	3374.	9395.	20395.	18992.	16312.	2043.	1.000	0.957
7.800	127.61	3389.	9231.	20050.	18671.	16036.	2037.	1.000	0.958
7.850	129.65	3404.	9071.	19712.	18356.	15766.	2030.	1.000	0.960
7.900	131.69	3418.	8914.	19381.	18048.	15501.	2023.	1.000	0.962
7.950	133.75	3432.	8761.	19058.	17747.	15242.	2016.	1.000	0.963
8.000	135.81	3446.	8612.	18742.	17452.	14990.	2009.	1.000	0.965

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
8.050	137.88	3460.	8466.	18433.	17165.	14743.	2003.	1.000	0.966
8.100	139.96	3474.	8323.	18132.	16884.	14502.	1996.	1.000	0.968
8.150	142.05	3487.	8184.	17837.	16610.	14266.	1989.	1.000	0.969
8.200	144.15	3500.	8048.	17549.	16342.	14026.	1983.	1.000	0.971
8.250	146.25	3513.	7915.	17268.	16080.	13811.	1976.	1.000	0.972
8.300	148.36	3525.	7785.	16993.	15824.	13591.	1970.	1.000	0.973
8.350	150.48	3538.	7658.	16724.	15574.	13376.	1964.	1.000	0.974
8.400	152.61	3550.	7534.	16462.	15329.	13166.	1957.	1.000	0.975
8.450	154.74	3562.	7413.	16205.	15090.	12960.	1951.	1.000	0.976
8.500	156.88	3574.	7294.	15953.	14856.	12759.	1945.	1.000	0.977
8.550	159.03	3586.	7179.	15708.	14627.	12563.	1939.	1.000	0.978
8.600	161.19	3597.	7065.	15467.	14403.	12371.	1932.	1.000	0.979
8.650	163.35	3608.	6955.	15232.	14184.	12183.	1926.	1.000	0.980
8.700	165.52	3620.	6846.	15002.	13970.	11999.	1920.	1.000	0.981
8.750	167.69	3630.	6740.	14777.	13761.	11819.	1914.	1.000	0.982
8.800	169.87	3641.	6637.	14557.	13556.	11643.	1908.	1.000	0.983
8.850	172.06	3652.	6535.	14342.	13355.	11470.	1903.	1.000	0.983
8.900	174.26	3662.	6436.	14131.	13159.	11302.	1897.	1.000	0.984
8.950	176.46	3673.	6339.	13925.	12967.	11137.	1891.	1.000	0.985
9.000	178.66	3683.	6245.	13723.	12779.	10975.	1885.	1.000	0.986
9.050	180.88	3693.	6152.	13525.	12595.	10813.	1879.	1.000	0.986
9.100	183.09	3702.	6061.	13332.	12415.	10663.	1874.	1.000	0.987
9.150	185.32	3712.	5973.	13143.	12239.	10512.	1868.	1.000	0.988
9.188	187.00	3719.	5907.	13003.	12109.	10400.	1864.	1.000	0.988

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	4.000	9.188
TRAVEL (IN):	13.64	187.00
VELOCITY (FT/S)	1237.	3719.
ACCELERATION (G):	26257.	5907.
BREECH PRESS (PSI):	55793.	13003.
MEAN PRESS (PSI):	51954.	12109.
BASE PRESS (PSI):	44623.	10400.
MEAN TEMP (K):	2637.	1864.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.354	0.988

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	211486528.	100.00
(1) INTERNAL GAS:	131203024.	62.04
(2) WORK AND LOSSES:	80283504.	37.96
(A) PROJECTILE KINETIC:	59803360.	28.28
(B) GAS KINETIC:	9825915.	4.65
(C) PROJECTILE ROTATIONAL:	30111.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	1007907.	0.48
(F) WORK DONE AGAINST AIR:	463070.	0.22
(G) HEAT CONVECTED TO BORE:	9153141.	4.33
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	0.884
CHARGE WT/PROJECTILE WT:	0.516
PIEZOMETRIC EFFICIENCY:	0.415
EXPANSION RATIO:	7.890

Test Case 3

The purpose here is to illustrate how to change the trajectory print and how to use the MULT function to alter one of the outputs. Projectile velocity, normally given in *feet/second*, has been multiplied by 12 and is now in units of *inches/second.* Three pressure gage locations have been added, one at thirty inches from projectile base (toward the breech), the second at original projectile base position, and the third at 10 inches of travel. After projectile exit, IBHVG2 also prints the blowdown phase of the shot, showing a rarefaction wave (pressure relief) moving from muzzle exit to breech.

Another complete ballistic calculation is initiated after the first solution and uses much of the previous input. The $SAVE feature enables IBHVG2 to carry over values from the previous run except those parameters specifically given in the $SAVE deck. Trajectory display is set back to default outputs, and blowdown phase dropped. Burning rate inputs have been changed for the second $PROP deck from the ALPHA/BETA method to an array of pressure/rate points. The $PARA deck is shown, where the charge weight of the second propellant (NTH=2) is varied from 25 through 27 by increments of 0.2 pounds. On the output, after the trajectory and summary information from the first iteration (CHWT=25), a table of values is printed showing iterated charge weights, maximum pressure, velocity and pressure at muzzle exit, propellant fractions burned and the point in travel where each propellant burned out (X@Z=1). Each line of output here represents an entire IBHVG2 calculation where only the charge weight input is changed from one run to the next.

```
$COMM
   IBHVG2 BENCHMARK TEST CASE 3

 -  SHOW TRAJECTORY PRINT OPTIONS, GUN TUBE GAUGE PRINTS, BLOWDOWN PHASE
 -  SHOW 'SAVE' FEATURE ; CHANGE PRINT OPTION AND BURN-RATE INPUTS;
 -  SHOW SMALL PARAMETRIC STUDY ON CHARGE WEIGHT FOR PROPELLANT 2, AND
     USE DEFAULT OUTPUTS FOR CHARGE WEIGHT VARIATIONS (PMAX,VMUZ,PMUZ,X@Z=1)

  'TDIS' VALUES USED WITH SPECIAL PRINT OPTION  - POPT(2)=2
$TDIS
 SHOW='TIME' REMK='TIME (MS)'
$TDIS
 SHOW='TRAV' REM1='TRAVEL (INCHES)'
$TDIS
  SHOW='VEL' REM1='VELOCITY (IN/SEC)' MULT=12.   $ IF MULT=1, THEN VEL=FT/SEC
$TDIS
 SHOW='ACCL' REMK='ACCEL (GRAV)'
$TDIS
 SHOW='FRCR' REM1='FRICTION (PSI)'
$TDIS
 SHOW='BRCH' REM1='BREECH PRESSURE (PSI)'
$TDIS
 SHOW='BASE' REM1='BASE PRESSURE (PSI)'
$TDIS
 SHOW='TBAR' REM1='MEAN TEMP (DEG K)'
$TDIS
 SHOW='WTB(1)' REM1='PROP 1 (LBS BRNED)'
$TDIS
 SHOW='WTB(2)' REMK='PROP 2 (LBS BRNED)'
$TDIS
 SHOW='WTB(3)' REM1='PROP 3 (LBS BRNED)'

$HEAT
  TSHL=0.00384

$COMM
```

```
  GET MAXIMUM PRESSURES AT GAGE LOCATIONS - BREECH,
    ORIGINAL PROJECTILE BASE, AND AT 10 INCHES OF TRAVEL
$GUN
 NAME='155-MM 198'      CHAM=1150     GRVE=6.2     LAND=6.1
G/L=1.66 TRAV=205. TWST=20  NGAG=3 GLOC=-30.,0.,10. CLEN=30.

$PROJ
   NAME='M549A1'  PRWT=96
$RESI
 NPTS=7 TRAV=0,0.4,1.,1.55,2.05,4.5,200
 PRES=250,3350,4950,3625,3250,2500,1500

$COMM
   INVOKE SPECIAL TRAJECTORY PRINT OPTION - POPT(2)=2
   CALCULATE AND PRINT BLOWDOWN PHASE - POPT(4)=1
$INFO
   POPT=1,2,1,1,0
   RUN="NEAR-STANDARD M203/M549"

$PRIM
   NAME='BLK POWDER'    CHWT=0.0154
   GAMA=1.25   FORC=96000  COV=30   TEMP=2000
$PROP
   NAME='BLK POWDER'    CHWT=0.2976    GRAN='CORD'
   LEN=0.198    DIAM=0.098
   RHO=0.06     GAMA=1.25    FORC=96000   COV=30    TEMP=2000
   ALPH=0.0     BETA=50      EROS=0.00000
$PROP
   NAME='M30A1'    CHWT=26.2    GRAN='7PF'
   LEN=0.9481   DIAM=0.4173  PD=0.0338        WI=0.078975    WO=0.078975
   RHO=0.0572   GAMA=1.243   FORC=356400      COV=28.5       TEMP=3040
   NTBL=0       ALPH=0.701   BETA=0.004025
$PROP
   NAME='NC TUBE' CHWT=0.5 GRAN='1PF' NTBL=0 ALPH=0 BETA=30
   LEN=28 DIAM=1.5 PD=1.25 WEB=0.125
   FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25
$END

$SAVE          $ KEEP PREVIOUS INPUTS EXCEPT FOR FOLLOWING VALUES

$COMM
   CHANGE TRAJECTORY PRINT OPTION AND TITLE
$INFO
   POPT=1,1,1,0,1   RUN='M203/M549  TABULAR B/R DATA'

$PROP          $ NO CHANGES IN FIRST PROPELLANT DECK
$PROP          $ CHANGE BURNING RATE SPECIFICATION METHOD
   NTBL=4 PR4L=1000,5000,10000,30000 BR4L=0.5102,1.577,2.563,5.536

$COMM
   ADD PARAMETRIC VARIATION ON CHARGE WEIGHT FOR SECOND PROPELLANT
$PARA
   VARY='CHWT' DECK='PROP' NTH=2 FROM=25 TO=27 BY=0.2
$END
```

Producing the following output:

```
ERRTOL=   4.768372E-07

CARD    1 --> $COMM
CARD    2 -->    IBHVG2 BENCHMARK TEST CASE 3
CARD    3 -->
CARD    4 -->  -  SHOW TRAJECTORY PRINT OPTIONS, GUN TUBE GAUGE PRINTS, BLOWDOWN PHASE
CARD    5 -->  -  SHOW 'SAVE' FEATURE ; CHANGE PRINT OPTION AND BURN-RATE INPUTS;
CARD    6 -->  -  SHOW SMALL PARAMETRIC STUDY ON CHARGE WEIGHT FOR PROPELLANT 2, AND
CARD    7 -->       USE DEFAULT OUTPUTS FOR CHARGE WEIGHT VARIATIONS (PMAX,VMUZ,PMUZ,XBZ=1)
CARD    8 -->
CARD    9 -->    'TDIS' VALUES USED WITH SPECIAL PRINT OPTION  - POPT(2)=2
CARD   10 --> $TDIS
CARD   11 -->   SHOW='TIME' REMK='TIME (MS)'
CARD   12 --> $TDIS
CARD   13 -->   SHOW='TRAV' REM1='TRAVEL (INCHES)'
CARD   14 --> $TDIS
CARD   15 -->    SHOW='VEL' REM1='VELOCITY (IN/SEC)' MULT=12.   $ IF MULT=1, THEN VEL=FT/SEC
CARD   16 --> $TDIS
CARD   17 -->   SHOW='ACCL' REMK='ACCEL (GRAV)'
CARD   18 --> $TDIS
CARD   19 -->   SHOW='FRCR' REM1='FRICTION (PSI)'
CARD   20 --> $TDIS
CARD   21 -->   SHOW='BRCH' REM1='BREECH PRESSURE (PSI)'
CARD   22 --> $TDIS
CARD   23 -->   SHOW='BASE' REM1='BASE PRESSURE (PSI)'
CARD   24 --> $TDIS
CARD   25 -->   SHOW='TBAR' REM1='MEAN TEMP (DEG K)'
CARD   26 --> $TDIS
CARD   27 -->   SHOW='WTB(1)' REM1='PROP 1 (LBS BRNED)'
CARD   28 --> $TDIS
CARD   29 -->   SHOW='WTB(2)' REMK='PROP 2 (LBS BRNED)'
CARD   30 --> $TDIS
CARD   31 -->   SHOW='WTB(3)' REM1='PROP 3 (LBS BRNED)'
CARD   32 -->
CARD   33 --> $HEAT
CARD   34 -->   TSHL=0.00384
CARD   35 -->
CARD   36 --> $COMM
CARD   37 -->   GET MAXIMUM PRESSURES AT GAGE LOCATIONS - BREECH,
CARD   38 -->      ORIGINAL PROJECTILE BASE, AND AT 10 INCHES OF TRAVEL
CARD   39 --> $GUN
CARD   40 -->  NAME='155-MM 198'      CHAM=1150     GRVE=6.2     LAND=6.1
CARD   41 --> G/L=1.66 TRAV=205. TWST=20  NGAG=3 GLOC=-30.,0.,10. CLEN=30.
CARD   42 -->
CARD   43 --> $PROJ
CARD   44 -->     NAME='M549A1'  PRWT=96
CARD   45 --> $RESI
CARD   46 -->  NPTS=7 TRAV=0,0.4,1.,1.55,2.05,4.5,200
CARD   47 -->  PRES=250,3350,4950,3625,3250,2500,1500
CARD   48 -->
CARD   49 --> $COMM
CARD   50 -->    INVOKE SPECIAL TRAJECTORY PRINT OPTION - POPT(2)=2
CARD   51 -->    CALCULATE AND PRINT BLOWDOWN PHASE - POPT(4)=1
CARD   52 --> $INFO
CARD   53 -->    POPT=1,2,1,1,0
CARD   54 -->    RUN="NEAR-STANDARD M203/M549"
CARD   55 -->
```

```
CARD  56 --> $PRIM
CARD  57 -->    N[illegible]   LK POWDER'    CHWT=0.0154
CARD  58 -->    G[illegible]   25   FORC=96000  COV=30   TEMP=2000
CARD  59 --> $PRO[illegible]
CARD  60 -->    NA[illegible] 'BLK POWDER'    CHWT=0.2976     GRAN='[illegible]ORD'
CARD  61 -->    LEN=0.198      DIAM=0.098
CARD  62 -->    RHO=0.06       GAMA=1.25    FORC=96000   COV=[illegible]0   TEMP=2000
CARD  63 -->    ALPH=0.0       BETA=50      EROS=0.00000
CARD  64 --> $PROP
CARD  65 -->    NAME='M30A1'    CHWT=26.2    GRAN='7PF'
CARD  66 -->    LEN=0.9481   DIAM=0.4173  PD=0.03[illegible]      WI=0.078975   WO=0.078975
CARD  67 -->    RHO=0.0572   GAMA=1.243   FORC=356400     COV=28.[illegible]       TEMP=3040
CARD  68 -->    NTBL=0        ALPH=0.701   BETA=0.004025
CARD  69 --> $PROP
CARD  70 -->    NAME='NC TUBE' CHWT=0.5 GRAN='1PF' NTBL=0 ALPH[illegible]     [illegible]=50
CARD  71 -->    LEN=28 DIAM=1.5 PD=1.25 WEB=0.125
CARD  72 -->    FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25
CARD  73 --> $END
```

- GUN TUBE -

TYPE: 155-MM 198		CHAMBER VOLUME (IN3):	1150.00	TRAVEL (IN):	205.00
GROOVE DIAMETER (IN):	6.200	LAND DIAMETER (IN):	6.100	GROOVE/LAND RATIO (-):	1.660
TWIST (CALS/TURN):	20.0	BORE AREA (IN2):	29.8275	HEAT-LOSS OPTION:	1
SHELL THICKNESS (IN):	0.003840	SHELL CP (IN-LB/LB-K):	1848.0	SHELL DENSITY (LB/IN3):	0.2840
INITIAL SHELL TEMP (K):	293.	AIR HO (IN-LB/IN2-S-K):	0.06480		
NO. GAGES:	3	CHAMBER LENGTH (IN):	30.00		

I	LOCATION (IN)	I	LOCATION (IN)	I	LOCATION (IN)
1	-30.00	2	0.00	3	10.00

- PROJECTILE -

TYPE: M549A1		TOTAL WEIGHT (LB):	96.000	WEIGHT PREDICTOR OPTION:	0

- RESISTANCE -

AIR RESISTANCE OPTION:		1	WALL HEATING FRACTION:		0.000	FRICTION TABLE LENGTH:		7
I	TRAVEL (IN)	PRESSURE (PSI)	I	TRAVEL (IN)	PRESSURE (PSI)	I	TRAVEL (IN)	PRESSURE (PSI)
1	0.00	250.	4	1.55	3625.	6	4.50	2500.
2	0.40	3350.	5	2.05	3250.	7	200.00	1500.
3	1.00	4950.						

- GENERAL -

MAX TIME STEP (S):	0.000100	PRINT STEP (S):	0.000000	MAX RELATIVE ERROR (-):	0.00200
PRINT OPTIONS:	1 2 1 1 0 1	STORE OPTION:	0	CONSTANT-PRESSURE OPTION:	0
GRADIENT MODEL: LAGRANGIAN					

- RECOIL -

RECOIL OPTION:	0	TYPE:		RECOILING WEIGHT (LB):	0.

- PRIMER -

TYPE: BLK POWDER		GAMMA (-):	1.2500	FORCE (FT-LB/LB):	96000.
COVOLUME (IN3/LB):	30.000	FLAME TEMP (K):	2000.0	WEIGHT (LB):	0.015400

- CHARGE 1 -

TYPE: BLK POWDER		GRAINS:	3321.0	CORD	WEIGHT (LB): 0.2976
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S): 0.00000E+00
GRAIN LENGTH (IN):	0.19800	GRAIN DIAMETER (IN):		0.09800	

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06000	------	------	------	0.06000
GAMMA (-):	------	------	------	1.2500	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	96000.	------	------	------	96000.
COVOLUME (IN3/LB):	------	------	------	30.000	------	------	------	30.000
FLAME TEMP (K):	------	------	------	2000.0	------	------	------	2000.0
BURNING RATE EXPS:	------	------	------	0.0000	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	50.0000000	------	------	------	50.0000000

- CHARGE 2 -

TYPE: M30A1		GRAINS:	3702.4 7PF	WEIGHT (LB):	26.2000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.94810	GRAIN DIAMETER (IN):	0.41730	PERF DIAMETER (IN):	0.03380
INNER WEB (IN):	0.07898	OUTER WEB (IN):	0.07898		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05720	------	------	------	0.05720
GAMMA (-):	------	------	------	1.2430	------	------	------	1.2430
FORCE (FT-LB/LB):	------	------	------	356400.	------	------	------	356400.
COVOLUME (IN3/LB):	------	------	------	28.500	------	------	------	28.500
FLAME TEMP (K):	------	------	------	3040.0	------	------	------	3040.0
BURNING RATE EXPS:	------	------	------	0.7010	------	------	------	0.7010
BURNING RATE COEFFS:	------	------	------	0.0040250	------	------	------	0.0040250

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05720
GAMMA (-):	------	------	------	1.2430
FORCE (FT-LB/LB):	------	------	------	356400.
COVOLUME (IN3/LB):	------	------	------	28.500
FLAME TEMP (K):	------	------	------	3040.0
BURNING RATE EXPS:	------	------	------	0.7010
BURNING RATE COEFFS:	------	------	------	0.0040250

- CHARGE 3 -

TYPE: NC TUBE		GRAINS:	0.97268 1PF	WEIGHT (LB):	0.5000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	28.00000	GRAIN DIAMETER (IN):	1.50000	PERF DIAMETER (IN):	1.25000
INNER WEB (IN):	0.12500	WEB RATIO:	1.0000		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES				PROPERTIES AT LAYER BOUNDARIES OF END SURFACES			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.03400	------	------	------	0.03400
GAMMA (-):	------	------	------	1.2500	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	180000.	------	------	------	180000.
COVOLUME (IN3/LB):	------	------	------	30.000	------	------	------	30.000
FLAME TEMP (K):	------	------	------	1553.0	------	------	------	1553.0
BURNING RATE EXPS:	------	------	------	0.0000	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	30.0000000	------	------	------	30.0000000

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			
	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.03400
GAMMA (-):	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	180000.
COVOLUME (IN3/LB):	------	------	------	30.000
FLAME TEMP (K):	------	------	------	1553.0
BURNING RATE EXPS:	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	30.0000000

```
TRAJECTORY VARIABLES: / 1/  TRAJ 1  TIME      TIME (MS)
                      / 2/  TRAJ 1  TRAV      TRAVEL (INCHES)
                      / 3/  TRAJ 1  VEL       VELOCITY (IN/SEC)
                      / 4/  TRAJ 1  ACCL      ACCEL (GRAV)
                      / 5/  TRAJ 1  FRCR      FRICTION (PSI)
                      / 6/  TRAJ 1  BRCH      BREECH PRESSURE (PSI
                      / 7/  TRAJ 1  BASE      BASE PRESSURE (PSI)
                      / 8/  TRAJ 1  TBAR      MEAN TEMP (DEG K)
                      / 9/  TRAJ 1  WTB(1)    PROP 1 (LBS BRNED)
                      /10/  TRAJ 1  WTB(2)    PROP 2 (LBS BRNED)
                      /11/  TRAJ 1  WTB(3)    PROP 3 (LBS BRNED)
```

/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/	/ 9/	/10/	/11/
0.	0.	0.	0.	26.407	26.407	26.407	2000.0	0.	0.	0.
0.95191E-01	0.45392E-09	0.	0.28446E-03	250.00	250.00	250.00	1930.6	0.66669E-01	0.54650E-02	0.22943E-01
SHOT-START PRESSURE ACHIEVED										
0.10000	0.71886E-08	0.31346E-02	3.3780	250.00	262.40	260.87	1933.1	0.69755E-01	0.59065E-02	0.24102E-01
0.20000	0.53071E-04	1.5284	76.405	250.41	530.92	496.32	1985.2	0.12812	0.18176E-01	0.48194E-01
0.30000	0.40276E-03	5.9640	153.83	253.12	817.89	748.23	2034.7	0.17603	0.35912E-01	0.72275E-01
0.40000	0.13480E-02	13.462	234.78	260.45	1122.4	1016.1	2081.2	0.21442	0.58764E-01	0.96346E-01
0.50000	0.32013E-02	24.146	318.69	274.81	1444.9	1300.6	2125.2	0.24423	0.86558E-01	0.12041
0.60000	0.62869E-02	38.123	405.13	298.72	1786.1	1602.7	2167.1	0.26641	0.11922	0.14446
0.70000	0.10939E-01	55.483	493.77	334.77	2147.6	1924.1	2207.1	0.28189	0.15673	0.16850
0.80000	0.17499E-01	76.306	584.35	385.62	2531.1	2266.5	2245.3	0.29162	0.19914	0.19253
0.98000	0.35238E-01	122.74	751.66	523.10	3282.9	2942.5	2309.4	0.29764	0.28805	0.23576
PROPELLANT 1 BURNED OUT										
1.0000	0.37751E-01	128.62	770.58	542.57	3371.8	3022.9	2316.2	0.29764	0.29895	0.24056
1.1000	0.52164E-01	160.25	866.91	654.27	3837.2	3444.7	2348.6	0.29764	0.35662	0.26456
1.2000	0.69926E-01	195.65	965.73	791.93	4337.7	3900.4	2378.9	0.29764	0.41972	0.28854
1.3000	0.91421E-01	234.90	1066.6	958.51	4874.5	4391.6	2407.2	0.29764	0.48849	0.31252
1.4000	0.11704	278.09	1168.9	1157.0	5448.8	4919.5	2433.6	0.29764	0.56314	0.33649
1.5000	0.14717	325.25	1272.1	1390.6	6061.5	5485.5	2458.5	0.29764	0.64392	0.36045
1.6000	0.18222	376.40	1375.8	1662.2	6713.9	6090.9	2481.7	0.29764	0.73105	0.38440
1.7000	0.22259	431.57	1479.3	1975.0	7406.9	6737.0	2503.6	0.29764	0.82480	0.40833
1.8000	0.26867	490.72	1582.1	2332.2	8141.4	7425.0	2524.0	0.29764	0.92539	0.43226
1.9000	0.32086	553.82	1683.5	2736.7	8918.3	8156.0	2543.2	0.29764	1.0331	0.45618
2.0000	0.37956	620.80	1783.0	3191.6	9738.6	8931.2	2561.2	0.29764	1.1482	0.48009
2.0833	0.43373	680.01	1912.0	3440.0	10460.	9594.7	2575.6	0.29764	1.2499	0.49934
PROPELLANT 3 BURNED OUT										
2.1000	0.44517	692.42	1940.7	3470.4	10596.	9717.6	2580.5	0.29764	1.2708	0.49934
2.2000	0.51827	770.78	2116.2	3665.4	11436.	10477.	2607.9	0.29764	1.4010	0.49934
2.3000	0.59955	856.03	2297.1	3882.1	12317.	11277.	2633.0	0.29764	1.5385	0.49934
2.4000	0.68971	948.36	2483.0	4122.6	13240.	12116.	2655.8	0.29764	1.6838	0.49934
2.5000	0.78947	1048.0	2673.3	4388.6	14205.	12994.	2676.6	0.29764	1.8371	0.49934
2.6000	0.89956	1155.0	2867.4	4682.1	15211.	13913.	2695.5	0.29764	1.9986	0.49934
2.7000	1.0207	1269.8	3094.4	4900.1	16263.	14861.	2712.6	0.29764	2.1685	0.49934
2.8000	1.1539	1396.9	3485.6	4579.2	17378.	15800.	2727.9	0.29764	2.3472	0.49934
2.9000	1.3006	1539.4	3896.7	4225.8	18534.	16770.	2741.6	0.29764	2.5349	0.49934
3.0000	1.4624	1698.3	4327.9	3836.1	19728.	17768.	2753.8	0.29764	2.7317	0.49934
3.1000	1.6408	1873.9	4736.9	3556.9	20950.	18806.	2764.5	0.29764	2.9379	0.49934
3.2000	1.8376	2064.2	5116.4	3409.3	22196.	19880.	2773.7	0.29764	3.1537	0.49934
3.3000	2.0542	2269.4	5506.4	3248.7	23468.	20975.	2781.5	0.29764	3.3792	0.49934
3.4000	2.2920	2489.3	5877.0	3175.9	24756.	22095.	2788.0	0.29764	3.6145	0.49934
3.5000	2.5525	2723.7	6253.6	3096.2	26060.	23228.	2793.2	0.29764	3.8598	0.49934
3.6000	2.8372	2972.6	6634.9	3009.0	27373.	24368.	2797.2	0.29764	4.1152	0.49934
3.7000	3.1475	3236.4	7019.1	2914.0	28689.	25511.	2800.0	0.29764	4.3807	0.49934
3.8000	3.4850	3515.1	7404.7	2810.7	30002.	26649.	2801.7	0.29764	4.6563	0.49934

TRAJECTORY VARIABLES:

/ 1/	TRAJ 1	TIME	TIME (MS)
/ 2/	TRAJ 1	TRAV	TRAVEL (INCHES)
/ 3/	TRAJ 1	VEL	VELOCITY (IN/SEC)
/ 4/	TRAJ 1	ACCL	ACLEL (GRAV)
/ 5/	TRAJ 1	FRCR	FRICTION (PSI)
/ 6/	TRAJ 1	BRCH	BREECH PRESSURE (PSI
/ 7/	TRAJ 1	BASE	BASE PRESSURE (PSI)
/ 8/	TRAJ 1	TBAR	MEAN TEMP (DEG K)
/ 9/	TRAJ 1	WTB(1)	PROP 1 (LBS BRNED)
/10/	TRAJ 1	WTB(2)	PROP 2 (LBS BRNED)
/11/	TRAJ 1	WTB(3)	PROP 3 (LBS BRNED)

/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/	/ 9/	/10/	/11/
3.9000	3.8510	3808.7	7789.8	2698.7	31304.	27777.	2802.2	0.29764	4.9419	0.49934
4.0000	4.2472	4117.1	8172.6	2577.4	32589.	28888.	2801.7	0.29764	5.2376	0.49934
4.1000	4.6750	4440.1	8536.2	2499.1	33847.	29981.	2800.3	0.29764	5.5431	0.49934
4.2000	5.1357	4776.4	8869.4	2496.7	35068.	31052.	2797.8	0.29764	5.8585	0.49934
4.3000	5.6307	5125.4	9191.7	2494.2	36250.	32087.	2794.5	0.29764	6.1834	0.49934
4.4000	6.1612	5486.6	9501.5	2491.5	37385.	33082.	2790.3	0.29764	6.5176	0.49934
4.5000	6.7284	5859.5	9796.9	2488.6	38467.	34031.	2785.2	0.29764	6.8609	0.49934
4.6000	7.3334	6243.5	10076.	2485.5	39491.	34929.	2779.5	0.29764	7.2131	0.49934
4.7000	7.9774	6637.9	10339.	2482.2	40452.	35770.	2773.0	0.29764	7.5736	0.49934
4.8000	8.6613	7042.2	10582.	2478.7	41344.	36552.	2765.9	0.29764	7.9423	0.49934
4.9000	9.3861	7455.5	10807.	2475.0	42165.	37271.	2758.2	0.29764	8.3187	0.49934
4.9805	10.0000	7794.3	10972.	2471.9	42772.	37803.	2751.7	0.29764	8.6270	0.49934
PRESSURE GAGE 3 EXPOSED										
5.0000	10.153	7877.0	11011.	2471.1	42911.	37925.	2750.0	0.29764	8.7023	0.49934
5.1000	10.962	8306.1	11194.	2466.9	43580.	38512.	2741.3	0.29764	9.0929	0.49934
5.2000	11.814	8741.8	11356.	2462.6	44172.	39030.	2732.2	0.29764	9.4899	0.49934
5.3000	12.710	9183.4	11497.	2458.0	44686.	39480.	2722.7	0.29764	9.8928	0.49934
5.4000	13.651	9630.0	11616.	2453.2	45122.	39862.	2712.9	0.29764	10.301	0.49934
5.5000	14.636	10081.	11715.	2448.2	45481.	40176.	2702.7	0.29764	10.715	0.49934
5.6000	15.667	10535.	11794.	2442.9	45766.	40425.	2692.4	0.29764	11.133	0.49934
5.7000	16.743	10992.	11852.	2437.4	45978.	40611.	2681.9	0.29764	11.555	0.49934
5.8000	17.866	11451.	11892.	2431.6	46121.	40735.	2671.2	0.29764	11.981	0.49934
5.9000	19.034	11911.	11914.	2425.7	46197.	40802.	2660.4	0.29764	12.410	0.49934
5.9715	19.897	12240.	11920.	2421.2	46212.	40815.	2652.7	0.29764	12.718	0.49934
LOCAL PRESSURE MAX DETECTED										
6.0000	20.248	12371.	11919.	2419.4	46210.	40813.	2649.6	0.29764	12.842	0.49934
6.1000	21.508	12832.	11908.	2413.0	46164.	40772.	2638.7	0.29764	13.276	0.49934
6.2000	22.814	13291.	11882.	2406.3	46064.	40683.	2627.8	0.29764	13.712	0.49934
6.3000	24.166	13750.	11842.	2399.4	45912.	40550.	2616.9	0.29764	14.150	0.49934
6.4000	25.564	14206.	11789.	2392.3	45714.	40375.	2606.1	0.29764	14.589	0.49934
6.5000	27.007	14661.	11725.	2384.9	45472.	40163.	2595.3	0.29764	15.029	0.49934
6.6000	28.496	15112.	11650.	2377.3	45192.	39917.	2584.6	0.29764	15.469	0.49934
6.7000	30.029	15561.	11566.	2369.4	44877.	39640.	2574.0	0.29764	15.910	0.49934
6.8000	31.608	16006.	11474.	2361.3	44531.	39335.	2563.5	0.29764	16.351	0.49934
6.9000	33.230	16447.	11373.	2353.0	44157.	39007.	2553.2	0.29764	16.791	0.49934
7.0000	34.897	16885.	11267.	2344.5	43759.	38657.	2543.0	0.29764	17.231	0.49934
7.1000	36.607	17318.	11154.	2335.8	43339.	38288.	2532.9	0.29764	17.671	0.49934
7.2000	38.361	17747.	11037.	2326.8	42902.	37904.	2523.0	0.29764	18.109	0.49934
7.3000	40.157	18171.	10915.	2317.6	42448.	37506.	2513.2	0.29764	18.546	0.49934
7.4000	41.995	18590.	10790.	2308.2	41983.	37096.	2503.6	0.29764	18.982	0.49934
7.5000	43.874	19005.	10663.	2298.6	41506.	36678.	2494.2	0.29764	19.416	0.49934
7.6000	45.795	19414.	10533.	2288.8	41021.	36252.	2484.9	0.29764	19.849	0.49934
7.7000	47.757	19819.	10401.	2278.7	40530.	35820.	2475.8	0.29764	20.280	0.49934
7.8000	49.759	20218.	10268.	2268.5	40034.	35384.	2466.9	0.29764	20.709	0.49934

TRAJECTORY VARIABLES:

/ 1/	TRAJ 1	TIME	TIME (MS)
/ 2/	TRAJ 1	TRAV	TRAVEL (INCHES)
/ 3/	TRAJ 1	VEL	VELOCITY (IN/SEC)
/ 4/	TRAJ 1	ACCL	ACCEL (GRAV)
/ 5/	TRAJ 1	FRCR	FRICTION (PSI)
/ 6/	TRAJ 1	BRCH	BREECH PRESSURE (PSI
/ 7/	TRAJ 1	BASE	BASE PRESSURE (PSI)
/ 8/	TRAJ 1	TBAR	MEAN TEMP (DEG K)
/ 9/	TRAJ 1	WTB(1)	PROP 1 (LBS BRNED)
/10/	TRAJ 1	WTB(2)	PROP 2 (LBS BRNED)
/11/	TRAJ 1	WTB(3)	PROP 3 (LBS BRNED)

/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/	/ 9/	/10/	/11/
7.9000	51.801	20612.	10134.	2258.1	39535.	34946.	2458.1	0.29764	21.136	0.49934
8.0000	53.881	21001.	10000.	2247.4	39034.	34506.	2449.5	0.29764	21.561	0.49934
8.1000	56.001	21385.	9866.2	2236.6	38533.	34066.	2441.1	0.29764	21.984	0.49934
8.2000	58.158	21764.	9732.3	2225.5	38033.	33626.	2432.8	0.29764	22.405	0.49934
8.3000	60.353	22137.	9574.7	2214.3	37445.	33110.	2423.7	0.29764	22.783	0.49934
8.4000	62.585	22503.	9386.9	2202.9	36747.	32496.	2413.3	0.29764	23.103	0.49934
8.5000	64.854	22862.	9134.7	2191.3	35995.	31836.	2402.3	0.29764	23.386	0.49934
8.6000	67.157	23213.	8974.1	2179.5	35212.	31148.	2390.9	0.29764	23.640	0.49934
8.7000	69.496	23556.	8758.7	2167.5	34412.	30445.	2379.2	0.29764	23.871	0.49934
8.8000	71.868	23890.	8541.0	2155.4	33602.	29735.	2367.4	0.29764	24.080	0.49934
8.9000	74.273	24216.	8322.8	2143.1	32791.	29022.	2355.4	0.29764	24.271	0.49934
9.0001	76.711	24533.	8105.5	2130.6	31983.	28313.	2343.3	0.29764	24.444	0.49934
9.1001	79.180	24842.	7890.2	2118.0	31182.	27609.	2331.1	0.29764	24.603	0.49934
9.2001	81.679	25143.	7677.6	2105.2	30391.	26914.	2318.9	0.29764	24.747	0.49934
9.3001	84.208	25435.	7468.4	2092.3	29612.	26230.	2306.7	0.29764	24.879	0.49934
9.4001	86.766	25720.	7263.1	2079.2	28847.	25558.	2294.5	0.29764	24.998	0.49934
9.5001	89.352	25997.	7062.1	2066.0	28098.	24900.	2282.4	0.29764	25.107	0.49934
9.6001	91.965	26266.	6865.6	2052.6	27365.	24256.	2270.2	0.29764	25.205	0.49934
9.7001	94.605	26527.	6673.9	2039.1	26649.	23627.	2258.1	0.29764	25.294	0.49934
9.8001	97.270	26782.	6487.1	2025.5	25952.	23014.	2246.1	0.29764	25.375	0.49934
9.9001	99.961	27029.	6306.0	2011.7	25275.	22419.	2234.1	0.29764	25.448	0.49934
10.000	102.68	27269.	6130.8	1997.8	24620.	21843.	2222.4	0.29764	25.517	0.49934
10.100	105.41	27503.	5961.4	1983.8	23985.	21286.	2210.7	0.29764	25.581	0.49934
10.200	108.18	27730.	5797.5	1969.7	23371.	20746.	2199.2	0.29764	25.640	0.49934
10.300	110.96	27951.	5639.2	1955.4	22777.	20224.	2187.8	0.29764	25.695	0.49934
10.400	113.77	28166.	5486.1	1941.1	22203.	19719.	2176.6	0.29764	25.746	0.49934
10.500	116.59	28375.	5338.3	1926.6	21647.	19230.	2165.5	0.29764	25.793	0.49934
10.600	119.44	28578.	5195.4	1912.1	21109.	18757.	2154.5	0.29764	25.836	0.49934
10.700	122.31	28776.	5057.3	1897.4	20589.	18299.	2143.7	0.29764	25.876	0.49934
10.800	125.20	28969.	4923.9	1882.6	20086.	17857.	2133.0	0.29764	25.913	0.49934
10.900	128.10	29157.	4795.0	1867.8	19600.	17429.	2122.4	0.29764	25.947	0.49934
11.000	131.03	29340.	4670.5	1852.8	19129.	17014.	2111.9	0.29764	25.979	0.49934
11.100	133.97	29518.	4550.2	1837.8	18674.	16613.	2101.6	0.29764	26.007	0.49934
11.200	136.93	29691.	4433.9	1822.6	18233.	16225.	2091.4	0.29764	26.033	0.49934
11.300	139.91	29861.	4321.6	1807.4	17807.	15850.	2081.3	0.29764	26.057	0.49934
11.400	142.90	30025.	4213.0	1792.1	17394.	15486.	2071.3	0.29764	26.078	0.49934
11.500	145.91	30186.	4108.0	1776.7	16995.	15134.	2061.5	0.29764	26.097	0.49934
11.600	148.94	30343.	4006.5	1761.2	16608.	14794.	2051.8	0.29764	26.114	0.49934
11.700	151.98	30496.	3908.4	1745.6	16233.	14463.	2042.1	0.29764	26.129	0.49934
11.800	155.04	30645.	3813.5	1730.0	15870.	14144.	2032.6	0.29764	26.143	0.49934
11.900	158.11	30791.	3721.7	1714.3	15519.	13834.	2023.2	0.29764	26.155	0.49934
12.000	161.20	30933.	3632.9	1698.5	15178.	13533.	2013.9	0.29764	26.165	0.49934
12.100	164.30	31071.	3547.1	1682.6	14849.	13242.	2004.7	0.29764	26.173	0.49934
12.200	167.41	31207.	3464.0	1666.7	14529.	12960.	1995.6	0.29764	26.180	0.49934

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TRAJECTORY VARIABLES: / 1/  TRAJ 1  TIME      TIME (MS)
                      / 2/  TRAJ 1  TRAV      TRAVEL (INCHES)
                      / 3/  TRAJ 1  VEL       VELOCITY (IN/SEC)
                      / 4/  TRAJ 1  ACCL      ACCEL (GRAV)
                      / 5/  TRAJ 1  FRCR      FRICTION (PSI)
                      / 6/  TRAJ 1  BRCH      BREECH PRESSURE (PSI
                      / 7/  TRAJ 1  BASE      BASE PRESSURE (PSI)
                      / 8/  TRAJ 1  TBAR      MEAN TEMP (DEG K)
                      / 9/  TRAJ 1  WTB(1)    PROP 1 (LBS BRNED)
                      /10/  TRAJ 1  WTB(2)    PROP 2 (LBS BRNED)
                      /11/  TRAJ 1  WTB(3)    PROP 3 (LBS BRNED)
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/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/	/ 9/	/10/	/11/
12.300	170.54	31339.	3383.6	1650.7	14219.	12686.	1986.7	0.29764	26.186	0.49934
12.400	173.68	31468.	3305.7	1634.6	13918.	12421.	1977.8	0.29764	26.190	0.49934
12.500	176.83	31595.	3230.4	1618.5	13626.	12163.	1969.0	0.29764	26.193	0.49934
12.600	180.00	31718.	3157.4	1602.3	13343.	11913.	1960.3	0.29764	26.195	0.49934
12.700	183.18	31839.	3086.8	1586.1	13069.	11671.	1951.7	0.29764	26.196	0.49934
12.717	183.71	31859.	3075.2	1583.3	13023.	11631.	1950.2	0.29764	26.196	0.49934
PROPELLANT 2 BURNED OUT										
12.800	186.36	31956.	3018.5	1569.8	12803.	11436.	1943.2	0.29764	26.196	0.49934
12.900	189.56	32072.	2952.5	1553.4	12545.	11208.	1934.8	0.29764	26.196	0.49934
13.000	192.78	32185.	2888.7	1537.0	12295.	10987.	1926.6	0.29764	26.196	0.49934
13.100	196.00	32295.	2827.1	1520.5	12054.	10773.	1918.5	0.29764	26.196	0.49934
13.200	199.23	32403.	2767.6	1503.9	11820.	10566.	1910.5	0.29764	26.196	0.49934
13.300	202.48	32509.	2706.5	1500.0	11592.	10366.	1902.6	0.29764	26.196	0.49934
13.377	205.00	32589.	2659.6	1500.0	11421.	10216.	1896.6	0.29764	26.196	0.49934
PROJECTILE EXIT										

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	5.972	13.377
TRAVEL (IN):	19.90	205.00
VELOCITY (FT/S)	1020.	2716.
ACCELERATION (G):	11920.	2660.
BREECH PRESS (PSI):	46212.	11421.
MEAN PRESS (PSI):	44413.	11019.
BASE PRESS (PSI):	40815.	10216.
MEAN TEMP (K):	2653.	1897.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.485	1.000
Z CHARGE 3 (-):	1.000	1.000

GAGE	AT (IN) WRT SOM	PMAX (PSI)
1	-30.00	46212.
2	0.00	43943.
3	10.00	42699.

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	466804736.	100.00
(1) INTERNAL GAS:	294272512.	63.04
(2) WORK AND LOSSES:	172532304.	36.96
(A) PROJECTILE KINETIC:	131932192.	28.26
(B) GAS KINETIC:	12374597.	2.65
(C) PROJECTILE ROTATIONAL:	1627647.	0.35
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	12313598.	2.64
(F) WORK DONE AGAINST AIR:	621945.	0.13
(G) HEAT CONVECTED TO BORE:	13662321.	2.93
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	0.650
CHARGE WT/PROJECTILE WT:	0.281
PIEZOMETRIC EFFICIENCY:	0.467
EXPANSION RATIO:	6.317

TIME (MS)	RAREFACTION WAVE LOC'N (IN)	BREECH PRESS (PSI)	MOMENTUM (LB-SEC)	RECOIL TRAVEL (IN)	RECOIL VEL (FT/S)
13.377	243.55	11421.	9236.	0.00	0.00
13.500	242.66	11166.	9277.	0.00	0.00
14.000	238.57	10217.	9436.	0.00	0.00
14.500	233.78	9392.	9582.	0.00	0.00
15.000	228.29	8670.	9717.	0.00	0.00
15.500	222.13	8034.	9842.	0.00	0.00
16.000	215.30	7470.	9957.	0.00	0.00
16.500	207.84	6967.	10065.	0.00	0.00
17.000	199.75	6517.	10165.	0.00	0.00
17.500	191.05	6113.	10259.	0.00	0.00
18.000	181.75	5747.	10348.	0.00	0.00
18.500	171.88	5416.	10431.	0.00	0.00
19.000	161.45	5115.	10509.	0.00	0.00
19.500	150.48	4839.	10584.	0.00	0.00
20.000	138.97	4587.	10654.	0.00	0.00
20.500	126.95	4356.	10720.	0.00	0.00
21.000	114.42	4143.	10784.	0.00	0.00
21.500	101.41	3946.	10844.	0.00	0.00
22.000	87.91	3764.	10902.	0.00	0.00
22.500	73.95	3595.	10956.	0.00	0.00
23.000	59.53	3438.	11009.	0.00	0.00
23.500	44.66	3291.	11059.	0.00	0.00
24.000	29.36	3155.	11107.	0.00	0.00
24.500	13.63	3027.	11153.	0.00	0.00
24.923	0.00	2926.	11191.	0.00	0.00

```
CARD  74 -->
CARD  75 --> $SAVE          $ KEEP PREVIOUS INPUTS EXCEPT FOR FOLLOWING VALUES
CARD  76 -->
CARD  77 --> $COMM
CARD  78 -->     CHANGE TRAJECTORY PRINT OPTION AND TITLE
CARD  79 --> $INFO
CARD  80 -->    POPT=1,1,1,0,1   RUN='M203/M549  TABULAR B/R DATA'
CARD  81 -->
CARD  82 --> $PROP          $ NO CHANGES IN FIRST PROPELLANT DECK
CARD  83 --> $PROP          $ CHANGE BURNING RATE SPECIFICATION METHOD
CARD  84 -->    NTBL=4 PR4L=1000,5000,10000,30000 BR4L=0.5102,1.577,2.563,5.536
CARD  85 -->
CARD  86 --> $COMM
CARD  87 -->    ADD PARAMETRIC VARIATION ON CHARGE WEIGHT FOR SECOND PROPELLANT
CARD  88 --> $PARA
CARD  89 -->    VARY='CHWT' DECK='PROP' NTH=2 FROM=25 TO=27 BY=0.2
CARD  90 --> $END
```

- GUN TUBE -

TYPE: 155-MM 198		CHAMBER VOLUME (IN3):	1150.00	TRAVEL (IN):	205.00
GROOVE DIAMETER (IN):	[illegible]	LAND DIAMETER (IN):	6.100	GROOVE/LAND RATIO (-):	1.660
TWIST (CALS/TURN):	20.0	BORE AREA (IN2):	29.8275	HEAT-LOSS OPTION:	1
SHELL THICKNESS (IN):	0.003840	SHELL CP (IN-LB/LB-K):	1848.0	SHELL DENSITY (LB/IN3):	0.2840
INITIAL SHELL TEMP (K):	293.	AIR HO (IN-LB/IN2-S-K):	0.06480		
NO. GAGES:	3	CHAMBER LENGTH (IN):	30.00		

I	LOCATION (IN)	I	LOCATION (IN)	I	LOCATION (IN)
1	-30.00	2	0.00	3	10.00

- PROJECTILE -

TYPE: M549A1		TOTAL WEIGHT (LB):	96.000	WEIGHT PREDICTOR OPTION:	0

- RESISTANCE -

AIR RESISTANCE OPTION:	1	WALL HEATING FRACTION:	0.000	FRICTION TABLE LENGTH:	7

I	TRAVEL (IN)	PRESSURE (PSI)	I	TRAVEL (IN)	PRESSURE (PSI)	I	TRAVEL (IN)	PRESSURE (PSI)
1	0.00	250.	4	1.55	3625.	6	4.50	2500.
2	0.40	3350.	5	2.05	3250.	7	200.00	1500.
3	1.00	4950.						

- GENERAL -

MAX TIME STEP (S):	0.000100	PRINT STEP (S):	0.000000	MAX RELATIVE ERROR (-):	0.00200
PRINT OPTIONS:	1 1 1 0 1 1	STORE OPTION:	0	CONSTANT-PRESSURE OPTION:	0
GRADIENT MODEL: LAGRANGIAN					

- RECOIL -

RECOIL OPTION:	0	TYPE:		RECOILING WEIGHT (LB):	0.

- PRIMER -

TYPE: BLK POWDER		GAMMA (-):	1.2500	FORCE (FT-LB/LB):	96000.
COVOLUME (IN3/LB):	30.000	FLAME TEMP (K):	2000.0	WEIGHT (LB):	0.015400

- CHARGE 1 -

TYPE: BLK POWDER		GRAINS:	3321.0	CORD	WEIGHT (LB):	0.2976
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.19800	GRAIN DIAMETER (IN):		0.09800		

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES				PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06000	------	------	------	0.06000
GAMMA (-):	------	------	------	1.2500	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	96000.	------	------	------	96000.
COVOLUME (IN3/LB):	------	------	------	30.000	------	------	------	30.000
FLAME TEMP (K):	------	------	------	2000.0	------	------	------	2000.0
BURNING RATE EXPS:	------	------	------	0.0000	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	50.0000000	------	------	------	50.0000000

- CHARGE 2 -

TYPE: M30A1		GRAINS:	3532.8 7PF	WEIGHT (LB):	25.0000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.94810	GRAIN DIAMETER (IN):	0.41730	PERF DIAMETER (IN):	0.03380
INNER WEB (IN):	0.07898	OUTER WEB (IN):	0.07898		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES				PROPERTIES AT LAYER BOUNDARIES OF END SURFACES			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05720	------	------	------	0.05720
GAMMA (-):	------	------	------	1.2430	------	------	------	1.2430
FORCE (FT-LB/LB):	------	------	------	356400.	------	------	------	356400.
COVOLUME (IN3/LB):	------	------	------	28.500	------	------	------	28.500
FLAME TEMP (K):	------	------	------	3040.0	------	------	------	3040.0
MEAN PRESSURES (PSI):	------	------	------	1000.0	------	------	------	1000.0
MEAN PRESSURES (PSI):	------	------	------	5000.0	------	------	------	5000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	30000.0	------	------	------	30000.0
BURNING RATES (IN/S):	------	------	------	0.51	------	------	------	0.51
BURNING RATES (IN/S):	------	------	------	1.58	------	------	------	1.58
BURNING RATES (IN/S):	------	------	------	2.56	------	------	------	2.56
BURNING RATES (IN/S):	------	------	------	5.54	------	------	------	5.54

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			
	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05720
GAMMA (-):	------	------	------	1.2430
FORCE (FT-LB/LB):	------	------	------	356400.
COVOLUME (IN3/LB):	------	------	------	28.500
FLAME TEMP (K):	------	------	------	3040.0
MEAN PRESSURES (PSI):	------	------	------	1000.0
MEAN PRESSURES (PSI):	------	------	------	5000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	30000.0
BURNING RATES (IN/S):	------	------	------	0.51
BURNING RATES (IN/S):	------	------	------	1.58
BURNING RATES (IN/S):	------	------	------	2.56
BURNING RATES (IN/S):	------	------	------	5.54

- CHARGE 3 -

TYPE: NC TUBE		GRAINS:	0.97268	1PF	WEIGHT (LB):	0.5000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	28.00000	GRAIN DIAMETER (IN):		1.50000	PERF DIAMETER (IN):	1.25[illegible]
INNER WEB (IN):	0.12500	WEB RATIO:		1.0000		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES				PROPERTIES AT LAYER BOUNDARIES OF END SURFACES			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.03400	------	------	------	0.03400
GAMMA (-):	------	------	------	1.2500	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	180000.	------	------	------	180000.
COVOLUME (IN3/LB):	------	------	------	30.000	------	------	------	30.000
FLAME TEMP (K):	------	------	------	1553.0	------	------	------	1553.0
BURNING RATE EXPS:	------	------	------	0.0000	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	30.0000000	------	------	------	30.0000000

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			
	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.03400
GAMMA (-):	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	180000.
COVOLUME (IN3/LB):	------	------	------	30.000
FLAME TEMP (K):	------	------	------	1553.0
BURNING RATE EXPS:	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	30.0000000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3
0.000	0.00	0.	0.	26.	26.	26.	2000.	0.000	0.000	0.000
0.099	0.00	0.	0.	250.	250.	250.	1925.	0.233	0.000	0.048
SHOT-START PRESSURE ACHIEVED										
0.100	0.00	0.	0.	251.	251.	251.	1926.	0.234	0.000	0.048
0.200	0.00	0.	70.	505.	495.	475.	1973.	0.431	0.001	0.096
0.300	0.00	0.	143.	774.	753.	712.	2019.	0.591	0.001	0.145
0.400	0.00	1.	218.	1056.	1025.	962.	2062.	0.720	0.002	0.193
0.500	0.00	2.	296.	1353.	1310.	1225.	2104.	0.821	0.003	0.241
0.600	0.01	3.	375.	1664.	1610.	1502.	2143.	0.895	0.004	0.289
0.700	0.01	4.	455.	1991.	1926.	1794.	2181.	0.947	0.006	0.337
0.800	0.02	6.	537.	2336.	2258.	2104.	2217.	0.980	0.007	0.385
0.980	0.03	9.	686.	3006.	2907.	2709.	2278.	1.000	0.010	0.472
PROPELLANT 1 BURNED OUT										
1.000	0.03	10.	702.	3085.	2983.	2781.	2285.	1.000	0.011	0.481
1.100	0.05	12.	787.	3496.	3383.	3156.	2316.	1.000	0.013	0.529
1.200	0.06	15.	873.	3937.	3811.	3559.	2345.	1.000	0.015	0.577
1.300	0.08	18.	960.	4409.	4270.	3993.	2373.	1.000	0.018	0.625
1.400	0.11	21.	1048.	4911.	4760.	4457.	2399.	1.000	0.020	0.673
1.500	0.13	25.	1137.	5445.	5281.	4953.	2423.	1.000	0.023	0.721
1.600	0.17	28.	1224.	6012.	5836.	5483.	2446.	1.000	0.026	0.769
1.700	0.20	33.	1311.	6613.	6424.	6046.	2468.	1.000	0.030	0.817
1.800	0.24	37.	1397.	7248.	7047.	6644.	2488.	1.000	0.033	0.865
1.900	0.29	42.	1481.	7918.	7705.	7278.	2507.	1.000	0.037	0.912
2.000	0.34	46.	1562.	8624.	8399.	7948.	2526.	1.000	0.041	0.960
2.083	0.39	51.	1627.	9238.	9003.	8534.	2540.	1.000	0.044	1.000
PROPELLANT 3 BURNED OUT										
2.100	0.40	52.	1641.	9351.	9115.	8641.	2545.	1.000	0.045	1.000
2.200	0.47	57.	1788.	10061.	9804.	9288.	2574.	1.000	0.050	1.000
2.300	0.54	63.	1939.	10806.	10526.	9967.	2600.	1.000	0.055	1.000
2.400	0.62	70.	2094.	11585.	11283.	10679.	2624.	1.000	0.060	1.000
2.500	0.71	77.	2253.	12399.	12074.	11424.	2646.	1.000	0.065	1.000
2.600	0.80	84.	2415.	13247.	12898.	12202.	2666.	1.000	0.070	1.000
2.700	0.91	92.	2579.	14129.	13757.	13013.	2684.	1.000	0.076	1.000
2.800	1.03	101.	2782.	15050.	14648.	13846.	2701.	1.000	0.083	1.000
2.900	1.15	110.	3133.	16024.	15572.	14669.	2716.	1.000	0.089	1.000
3.000	1 29	121.	3500.	17032.	16527.	15518.	2730.	1.000	0.096	1.000
3.100	1.44	133.	3885.	18072.	17512.	16391.	2742.	1.000	0.103	1.000
3.200	1.61	146.	4260.	19137.	18522.	17293.	2753.	1.000	0.110	1.000
3.300	1.79	160.	4594.	20219.	19557.	18232.	2763.	1.000	0.118	1.000
3.400	1.99	176.	4938.	21324.	20612.	19188.	2771.	1.000	0.126	1.000
3.500	2.22	192.	5270.	22444.	21684.	20164.	2778.	1.000	0.134	1.000
3.600	2.46	209.	5600.	23578.	22770.	21154.	2784.	1.000	0.143	1.000
3.700	2.72	228.	5935.	24720.	23864.	22152.	2789.	1.000	0.152	1.000
3.800	3.00	248.	6273.	25868.	24963.	23154.	2793.	1.000	0.162	1.000
3.900	3.31	268.	6613.	27016.	26062.	24154.	2795.	1.000	0.171	1.000
4.000	3.65	290.	6954.	28157.	27154.	25148.	2797.	1.000	0.181	1.000
4.100	4.01	313.	7294.	29288.	28236.	26132.	2797.	1.000	0.192	1.000
4.200	4.40	337.	7631.	30402.	29301.	27100.	2797.	1.000	0.203	1.000
4.300	4.82	362.	7938.	31489.	30344.	28054.	2796.	1.000	0.214	1.000
4.400	5.27	388.	8228.	32546.	31359.	28986.	2794.	1.000	0.225	1.000
4.500	5.75	415.	8508.	33569.	32342.	29887.	2791.	1.000	0.237	1.000
4.600	6.27	443.	8778.	34552.	33286.	30754.	2787.	1.000	0.249	1.000
4.700	6.82	472.	9036.	35492.	34188.	31582.	2782.	1.000	0.262	1.000
4.800	7.40	501.	9281.	36382.	35044.	32367.	2777.	1.000	0.274	1.000
4.900	8.02	532.	9511.	37220.	35849.	33105.	2771.	1.000	0.287	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3
5.000	8.68	563.	9726.	38002.	36599.	33794.	2765.	1.000	0.301	1.000
5.100	9.37	594.	9924.	38725.	37294.	34431.	2758.	1.000	0.314	1.000
5.186	10.00	622.	10082.	39299.	37845.	34937.	2752.	1.000	0.326	1.000
PRESSURE GAGE 3 EXPOSED										
5.200	10.10	626.	10106.	39387.	37929.	35014.	2751.	1.000	0.328	1.000
5.300	10.87	659.	10271.	39985.	38504.	35541.	2743.	1.000	0.342	1.000
5.400	11.69	693.	10418.	40520.	39017.	36012.	2734.	1.000	0.356	1.000
5.500	12.54	726.	10548.	40990.	39469.	36426.	2726.	1.000	0.371	1.000
5.600	13.43	760.	10660.	41396.	39858.	36703.	2717.	1.000	0.385	1.000
5.700	14.36	795.	10755.	41738.	40187.	37085.	2707.	1.000	0.400	1.000
5.800	15.34	830.	10832.	42018.	40456.	37331.	2698.	1.000	0.415	1.000
5.900	16.35	865.	10893.	42237.	40666.	37523.	2688.	1.000	0.430	1.000
6.000	17.41	900.	10938.	42397.	40819.	37664.	2678.	1.000	0.445	1.000
6.100	18.51	935.	10968.	42501.	40919.	37755.	2668.	1.000	0.461	1.000
6.200	19.66	970.	10983.	42551.	40967.	37799.	2658.	1.000	0.476	1.000
6.248	20.21	987.	10985.	42556.	40972.	37803.	2653.	1.000	0.484	1.000
LOCAL PRESSURE MAX DETECTED										
6.300	20.84	1006.	10984.	42550.	40966.	37797.	2648.	1.000	0.492	1.000
6.400	22.07	1041.	10971.	42501.	40918.	37754.	2637.	1.000	0.508	1.000
6.500	23.34	1076.	10947.	42407.	[illegible]828.	37670.	2627.	1.000	0.523	1.000
6.600	24.65	1112.	10912.	42272.	[illegible]698.	37551.	2617.	1.000	0.539	1.000
6.700	26.01	1147.	10865.	42099.	[illegible]531.	37397.	2607.	1.000	0.555	1.000
6.800	27.41	1182.	10810.	41890.	4[illegible]331.	37212.	2597.	1.000	0.571	1.000
6.900	28.84	1216.	10745.	41649.	40099.	36999.	2586.	1.000	0.587	1.000
7.000	30.33	1251.	10673.	41379.	39839.	36760.	2576.	1.000	0.603	1.000
7.100	31.85	1285.	10593.	41082.	39554.	36499.	2567.	1.000	0.618	1.000
7.200	33.41	1319.	10507.	40763.	39247.	36216.	2557.	1.000	0.634	1.000
7.300	35.01	1353.	10416.	40422.	38920.	35915.	2547.	1.000	0.650	1.000
7.400	36.66	1386.	10320.	40064.	38575.	35598.	2538.	1.000	0.666	1.000
7.500	38.34	1419.	10219.	39689.	38215.	35268.	2528.	1.000	0.682	1.000
7.600	40.06	1452.	10114.	39301.	37842.	34925.	2519.	1.000	0.698	1.000
7.700	41.82	1484.	10007.	38902.	37458.	34572.	2510.	1.000	0.713	1.000
7.800	43.62	1516.	9897.	38492.	37065.	34210.	2501.	1.000	0.729	1.000
7.900	45.46	1548.	9785.	38075.	36664.	33841.	2492.	1.000	0.745	1.000
8.000	47.34	1579.	9671.	37652.	36257.	33467.	2483.	1.000	0.760	1.000
8.100	49.25	1610.	9556.	37223.	35845.	33088.	2475.	1.000	0.776	1.000
8.200	51.20	1641.	9439.	36791.	35430.	32707.	2466.	1.000	0.791	1.000
8.300	53.19	1671.	9323.	36357.	35013.	32323.	2458.	1.000	0.807	1.000
8.400	55.21	1701.	9206.	35922.	34594.	31938.	2450.	1.000	0.822	1.000
8.500	57.27	1730.	9089.	35486.	34175.	31554.	2442.	1.000	0.837	1.000
8.600	59.37	1759.	8972.	35051.	33757.	31169.	2434.	1.000	0.852	1.000
8.700	61.50	1788.	8847.	34584.	33303.	30756.	2426.	1.000	0.867	1.000
8.800	63.66	1816.	8688.	33996.	32743.	30237.	2416.	1.000	0.879	1.000
8.900	65.86	1844.	8515.	33356.	32128.	29671.	2406.	1.000	0.889	1.000
9.000	68.08	1871.	8334.	32686.	31484.	29080.	2395.	1.000	0.899	1.000
9.100	70.35	1898.	8148.	31998.	30823.	28472.	2384.	1.000	0.[illegible]08	1.000
9.200	72.64	1924.	79[illegible]0.	31300.	30152	27856.	2373.	1.000	0.915	1.000
9.300	74.96	1949.	7770.	30598.	29477.	27235.	2362.	1.000	0.923	1.000
9.400	77.32	1974.	7581.	29896.	28802.	26615.	2351.	1.000	0.929	1.000
9.500	79.70	1998.	7392.	29197.	28131.	25999.	2339.	1.000	0.935	1.000
9.600	82.11	2021.	7206.	28506.	27466.	25388.	2328.	1.000	0.941	1.000
9.700	84.55	2044.	7022.	27823.	26810.	24784.	2316.	1.000	0.946	1.000
9.800	87.02	2067.	6840.	27150.	26163.	24190.	2305.	1.000	0.951	1.000
9.900	89.51	2088.	6662.	26489.	25528.	23606.	2293.	1.000	0.955	1.000
10.000	92.03	2110.	6488.	25840.	24905.	23033.	2282.	1.000	0.959	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3
10.100	94.57	2130.	6317.	25206.	24294.	22472.	2270.	1.000	0.962	1.000
10.200	97.14	2150.	6150.	24585.	23698.	21924.	2259.	1.000	0.966	1.000
10.300	99.73	2170.	5987.	23979.	23115.	21388.	2247.	1.000	0.968	1.000
10.400	102.35	2189.	5829.	23389.	22548.	20867.	2236.	1.000	0.971	1.000
10.500	104.99	2207.	5676.	22817.	21998.	20361.	2225.	1.000	0.974	1.000
10.600	107.65	2225.	5527.	22262.	21465.	19870.	2214.	1.000	0.976	1.000
10.700	110.33	2243.	5383.	21724.	20947.	19395.	2203.	1.000	0.978	1.000
10.800	113.03	2260.	5243.	21202.	20446.	18933.	2192.	1.000	0.980	1.000
10.900	115.75	2277.	5108.	20697.	19960.	18486.	2181.	1.000	0.982	1.000
11.000	118.49	2293.	4978.	20206.	19488.	18053.	2171.	1.000	0.984	1.000
11.100	121.25	2309.	4851.	19731.	19032.	17632.	2160.	1.000	0.985	1.000
11.200	124.03	2324.	4728.	19271.	18589.	17225.	2150.	1.000	0.987	1.000
11.300	126.83	2339.	4610.	18825.	18160.	16830.	2140.	1.000	0.988	1.000
11.400	129.65	2354.	4495.	18392.	17744.	16447.	2130.	1.000	0.990	1.000
11.500	132.48	2368.	4384.	17973.	17341.	16076.	2120.	1.000	0.991	1.000
11.600	135.33	2382.	4276.	17567.	16950.	15717.	2110.	1.000	0.992	1.000
11.700	138.20	2396.	4172.	17173.	16571.	15368.	2100.	1.000	0.993	1.000
11.800	141.08	2409.	4071.	16791.	16204.	15030.	2090.	1.000	0.994	1.000
11.900	143.98	2422.	3973.	16421.	15848.	14702.	2081.	1.000	0.995	1.000
12.000	146.89	2435.	3879.	16062.	15502.	14383.	2071.	1.000	0.996	1.000
12.100	149.82	2447.	3787.	15713.	15167.	14075.	2062.	1.000	0.996	1.000
12.200	152.76	2459.	3698.	15376.	14842.	13775.	2053.	1.000	0.997	1.000
12.300	155.72	2471.	3612.	15048.	14527.	13485.	2044.	1.000	0.997	1.000
12.400	158.69	2482.	3529.	14730.	14221.	13203.	2035.	1.000	0.998	1.000
12.500	161.68	2493.	3449.	14421.	13924.	12929.	2026.	1.000	0.998	1.000
12.600	164.68	2504.	3370.	14122.	13636.	12663.	2017.	1.000	0.999	1.000
12.700	167.69	2515.	3295.	13831.	13356.	12405.	2008.	1.000	0.999	1.000
12.800	170.71	2526.	3221.	13549.	13084.	12155.	1999.	1.000	0.999	1.000
12.900	173.75	2536.	3150.	13274.	12820.	11911.	1991.	1.000	1.000	1.000
13.000	176.80	2546.	3081.	13008.	12564.	11675.	1982.	1.000	1.000	1.000
13.100	179.86	2556.	3014.	12749.	12314.	11445.	1974.	1.000	1.000	1.000
13.200	182.93	2565.	2950.	12498.	12072.	11221.	1966.	1.000	1.000	1.000
13.300	186.02	2575.	2887.	12253.	11837.	11004.	1957.	1.000	1.000	1.000
13.395	188.96	2583.	2829.	12027.	11619.	10803.	1950.	1.000	1.000	1.000
PROPELLANT 2 BURNED OUT										
13.400	189.11	2584.	2826.	12016.	11608.	10795.	1949.	1.000	1.000	1.000
13.500	192.21	2593.	2767.	11785.	11386.	10588.	1941.	1.000	1.000	1.000
13.600	195.33	2602.	2710.	11562.	11171.	10389.	1933.	1.000	1.000	1.000
13.700	198.46	2610.	2654.	11345.	10962.	10196.	1926.	1.000	1.000	1.000
13.800	201.60	2619.	2598.	11134.	10759.	10009.	1918.	1.000	1.000	1.000
13.900	204.74	2627.	2542.	10929.	10562.	9829.	1910.	1.000	1.000	1.000
13.908	205.00	2628.	2537.	10912.	10546.	9814.	1910.	1.000	1.000	1.000

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	6.248	13.908
TRAVEL (IN):	20.21	205.00
VELOCITY (FT/S)	987.	2628.
ACCELERATION (G):	10985.	2537.
BREECH PRESS (PSI):	42556.	10912.
MEAN PRESS (PSI):	40972.	10546.
BASE PRESS (PSI):	37803.	9814.
MEAN TEMP (K):	2653.	1910.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.484	1.000
Z CHARGE 3 (-):	1.000	1.000

GAGE	AT (IN) WRT SOM	PMAX (PSI)
1	-30.00	42556.
2	0.00	40581.
3	10.00	39492.

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	445809920.	100.00
(1) INTERNAL GAS:	283111168.	63.50
(2) WORK AND LOSSES:	162698832.	36.50
(A) PROJECTILE KINETIC:	123518720.	27.71
(B) GAS KINETIC:	11070795.	2.48
(C) PROJECTILE ROTATIONAL:	1523850.	0.34
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	12313684.	2.76
(F) WORK DONE AGAINST AIR:	584053.	0.13
(G) HEAT CONVECTED TO BORE:	13687733.	3.07
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	0.621
CHARGE WT/PROJECTILE WT:	0.269
PIEZOMETRIC EFFICIENCY:	0.475
EXPANSION RATIO:	6.317

PARAMETRIC VARIABLES: / 1/ PROP 2 CHWT

/1/	PMAX	VMUZ	PMUZ	Z(1)	XQZ=1	Z(2)	XQZ=1	Z(3)	XQZ=1
25.00	42556.	2628.	9814.	1.000	0.02	1.000	186.02	1.000	0.34
25.20	43147.	2642.	9881.	1.000	0.02	1.000	185.62	1.000	0.35
25.40	43745.	2657.	9949.	1.000	0.02	1.000	185.19	1.000	0.36
25.60	44349.	2672.	10015.	1.000	0.02	1.000	184.72	1.000	0.36
25.80	44961.	2687.	10086.	1.000	0.02	1.000	184.25	1.000	0.37
26.00	45582.	2701.	10151.	1.000	0.02	1.000	183.72	1.000	0.37
26.20	46208.	2716.	10217.	1.000	0.02	1.000	183.17	1.000	0.38
26.40	46845.	2731.	10288.	1.000	0.02	1.000	182.60	1.000	0.39
26.60	47491.	2745.	10350.	1.000	0.02	1.000	181.98	1.000	0.39
26.80	48142.	2760.	10415.	1.000	0.02	1.000	178.12	1.000	0.40
27.00	48802.	2775.	10485.	1.000	0.02	1.000	177.45	1.000	0.41

Test Case 4

This run was used in a case study for a design of an incremental charge concept. It is included because it illustrates the utility of a well-documented input deck. All keywords are in uppercase, but the comments are in lowercase and spaced appropriately. The propelling charge is quite involved, requiring five different propellant decks. It should be noted that the combustible and non-combustible tubes were modeled as a propellant in IBHVG2.

```
$COMM
     IBHVG2 BENCHMARK TEST 4
        Showing acceptable uses of lower-case characters
        Showing five propellants, including two non-burning charges
        Shows iteration on fifth charge web to find PMAX=45kpsi

     Changing Burning Data     M30/M9     Zone 5

      -------------------------------------------------
        This run is to determine nominal parameter values
        by comparing the results with the "BARE INCREMENT"
        baseline.
      -------------------------------------------------

       ** DECK as of 14 Mar, 1630 hours

      -------------------------------------------------


$HEAT
    TSHL=0.00384

$GUN
     NAME='155-MM 198'      CHAM=1150     GRVE=6.2     LAND=6.1
     G/L=1.66 TRAV=205. TWST=20

$PROJ
     NAME='M549A1'  PRWT=96

$RESI
     NPTS=8
    TRAV=  0,  0.4,   1.,  1.55, 2.05,  4.5,   20,  200
    PRES=250, 2000, 3500, 2000, 1000,  500,  500,  500

$INFO
    POPT=1,1,1,0,1
    RUN="Incremental Charge Design   M30-M9"


$PRIM             $ Primer

    NAME='BLK POWDER'    $ Class 5 Black Powder
    CHWT=0.0154
    GAMA=1.25   FORC=96000   COV=30   TEMP=2000


$PROP             $ Igniter Function

    NAME='BLACK POWDER' $ Bag of black powder with each increment
    CHWT=0.3125         $ 5 ozs, 1 oz per increment
    GRAN='CORD'
    LEN=0.198  DIAM=0.098  RHO=0.06  GAMA=1.25  FORC=96000
    COV=30  TEMP=2000  ALPH=0.0  BETA=50.0   EROS=0.0


$PROP             $ Inner Tube

    NAME='NC TUBE'    $ Nitrocellulose Tube (Non-Combustible)
    GRAN='1PF'
    FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25
```

```
    NTBL=0 ALPH=0.00001 BETA=0.00001
    LEN=5.75
    PD=1.6875
    DIAM=2.0
    WEB=0.15625
    CW=0.3125


$PROP       $ Outer Tube -- does not really exist

    NAME='NC TUBE'    $ Nitrocellulose Tube (Non-Combustible)
    GRAN='1PF'
    FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25
    NTBL=0 ALPH=0.00001 BETA=0.00001
    GLEN=5.75
    DIAM=5.9
    PD=5.89
    WEB=0.005
    CHWT=0.00005  $ effectively, this tube is fictitous


$PROP                  $ M9 Propellant Charge
   NAME='M9 HAIR'      $ Lot # 6961
   GRAN='CORD'
   RHO=0.06    GAMA=1.2078    FORC=392399    COV=27.365    TEMP=3860
   LEN=4.00    DIAM=0.0337
   NTBL = 4
   PR4L =  1000,  3000, 4000, 15000
   BR4L = 0.617,  1.68, 1.90,  6.13
   EROS=0.0
   CHWT=1.5


$PROP                  $ M30 Propellant Charge
   NAME='M30A1'        $ Lot # 7022G
   GRAN='1PF'
   RHO=0.0572   GAMA=1.243   FORC=356400    COV=28.5    TEMP=3040
   NTBL=4
   PR4L = 1000,   5000, 10000, 30000
   BR4L =  0.40,  1.35,  2.25,  5.56
   LEN=5.50
   DIAM=0.2572
   WEB=0.09235
   PD=0.0725
   CHWT=22.5

$PMAX

   VARY='WEB'  TRY1=0.09  TRY2=0.094  PMAX=45000. NTH=5

$END
```

Producing the following output:

```
ERRTOL=   4.768372E-07

CARD   1 --> $COMM
CARD   2 -->      IBHVG2 BENCHMARK TEST 4
CARD   3 -->         Showing acceptable uses of lower-case characters
CARD   4 -->         Showing five propellants, including two non-burning charges
CARD   5 -->         Shows iteration on fifth charge web to find PMAX=45kpsi
CARD   6 -->
CARD   7 -->      Changing Burning Data     M30/M9    Zone 5
CARD   8 -->
CARD   9 -->       ----------------------------------------------------
CARD  10 -->         This run is to determine nominal parameter values
CARD  11 -->         by comparing the results with the "BARE INCREMENT"
CARD  12 -->         baseline.
CARD  13 -->       ----------------------------------------------------
CARD  14 -->
CARD  15 -->        ** DECK as of 14 Mar, 1630 hours
CARD  16 -->
CARD  17 -->       ----------------------------------------------------
CARD  18 -->
CARD  19 -->
CARD  20 --> $HEAT
CARD  21 -->     TSHL=0.00384
CARD  22 -->
CARD  23 --> $GUN
CARD  24 -->      NAME='155-MM 198'      CHAM=1150     GRVE=6.2     LAND=6.1
CARD  25 -->      G/L=1.66 TRAV=205. TWST=20
CARD  26 -->
CARD  27 --> $PROJ
CARD  28 -->      NAME='M549A1'  PRWT=96
CARD  29 -->
CARD  30 --> $RESI
CARD  31 -->     NPTS=8
CARD  32 -->     TRAV=  0,  0.4,   1., 1.55, 2.05,  4.5,   20,  200
CARD  33 -->     PRES=250, 2000, 3500, 2000, 1000,  500,  500,  500
CARD  34 -->
CARD  35 --> $INFO
CARD  36 -->     POPT=1,1,1,0,1
CARD  37 -->     RUN="Incremental Charge Design   M30-M9"
CARD  38 -->
CARD  39 -->
CARD  40 -->
CARD  41 --> $PRIM              $ Primer
CARD  42 -->
CARD  43 -->     NAME='BLK POWDER'    $ Class 5 Black Powder
CARD  44 -->     CHWT=0.0154
CARD  45 -->     GAMA=1.25   FORC=96000   COV=30   TEMP=2000
CARD  46 -->
CARD  47 -->
CARD  48 -->
CARD  49 --> $PROP              $ Igniter Function
CARD  50 -->
CARD  51 -->     NAME='BLACK POWDER' $ Bag of black powder with each increment
CARD  52 -->     CHWT=0.3125        $ 5 ozs, 1 oz per increment
CARD  53 -->     GRAN='CORD'
CARD  54 -->     LEN=0.198  DIAM=0.098  RHO=0.06  GAMA=1.25  FORC=96000
CARD  55 -->     COV=30  TEMP=2000  ALPH=0.0  BETA=50.0   EROS=0.0
```

```
CARD  56 -->
CARD  57 -->
CARD  58 -->
CARD  59 --> $PROP              $ Inner Tube
CARD  60 -->
CARD  61 -->     NAME='NC TUBE'    $ Nitrocellulose Tube (Non-Combustible)
CARD  62 -->     GRAN='1PF'
CARD  63 -->     FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25
CARD  64 -->     NTBL=0 ALPH=0.00001 BETA=0.00001
CARD  65 -->     LEN=5.75
CARD  66 -->     PD=1.6875
CARD  67 -->     DIAM=2.0
CARD  68 -->     WEB=0.15625
CARD  69 -->     CW=0.3125
CARD  70 -->
CARD  71 -->
CARD  72 -->
CARD  73 -->
CARD  74 --> $PROP        $ Outer Tube -- does not really exist
CARD  75 -->
CARD  76 -->     NAME='NC TUBE'    $ Nitrocellulose Tube (Non-Combustible)
CARD  77 -->     GRAN='1PF'
CARD  78 -->     FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25
CARD  79 -->     NTBL=0 ALPH=0.00001 BETA=0.00001
CARD  80 -->     GLEN=5.75
CARD  81 -->     DIAM=5.9
CARD  82 -->     PD=5.89
CARD  83 -->     WEB=0.005
CARD  84 -->     CHWT=0.00005  $ effectively, this tube is fictitous
CARD  85 -->
CARD  86 -->
CARD  87 -->
CARD  88 --> $PROP                    $ M9 Propellant Charge
CARD  89 -->    NAME='M9 HAIR'      $ Lot # 6961
CARD  90 -->    GRAN='CORD'
CARD  91 -->    RHO=0.06    GAMA=1.2078   FORC=392399   COV=27.365   TEMP=3860
CARD  92 -->    LEN=4.00    DIAM=0.0337
CARD  93 -->    NTBL = 4
CARD  94 -->    PR4L =  1000,  3000, 4000, 15000
CARD  95 -->    BR4L = 0.617,  1.68, 1.90,  6.13
CARD  96 -->    EROS=0.0
CARD  97 -->    CHWT=1.5
CARD  98 -->
CARD  99 -->
CARD 100 --> $PROP                    $ M30 Propellant Charge
CARD 101 -->    NAME='M30A1'        $ Lot # 7022G
CARD 102 -->    GRAN='1PF'
CARD 103 -->    RHO=0.0572   GAMA=1.243   FORC=356400    COV=28.5   TEMP=3040
CARD 104 -->    NTBL=4
CARD 105 -->    PR4L = 1000,   5000, 10000, 30000
CARD 106 -->    BR4L =  0.40,  1.35,  2.25,  5.56
CARD 107 -->    LEN=5.50
CARD 108 -->    DIAM=0.2572
CARD 109 -->    WEB=0.09235
CARD 110 -->    PD=0.0725
```

```
CARD 111 -->    CHWT=22.5
CARD 112 -->
CARD 113 --> $PMAX
CARD 114 -->
CARD 115 -->    VARY='WEB'  TRY1=0.09  TRY2=0.094  PMAX=45000. NTH=5
CARD 116 -->
CARD 117 --> $END
```

```
------------
- GUN TUBE -
------------

 TYPE: 155-MM 198
 GROOVE DIAMETER (IN):          6.200    CHAMBER VOLUME (IN3):          1150.00    TRAVEL (IN):                   205.00
 TWIST (CALS/TURN):              20.0    LAND DIAMETER (IN):              6.100    GROOVE/LAND RATIO (-):          1.660
 SHELL THICKNESS (IN):       0.003840    BORE AREA (IN2):               29.8275    HEAT-LOSS OPTION:                   1
 INITIAL SHELL TEMP (K):         293.    SHELL CP (IN-LB/LB-K):          1848.0    SHELL DENSITY (LB/IN3):        0.2840
                                         AIR HO (IN-LB/IN2-S-K):        0.06480
--------------
- PROJECTILE -
--------------

 TYPE: M549A1                            TOTAL WEIGHT (LB):              96.000    WEIGHT PREDICTOR OPTION:            0

--------------
- RESISTANCE -
--------------

 AIR RESISTANCE OPTION:              1   WALL HEATING FRACTION:           0.000    FRICTION TABLE LENGTH:              8

  I   TRAVEL (IN)    PRESSURE (PSI)       I   TRAVEL (IN)    PRESSURE (PSI)        I   TRAVEL (IN)    PRESSURE (PSI)

  1      0.00            250.             4      1.55            2000.             7     20.00            500.
  2      0.40           2000.             5      2.05            1000.             8    200.00            500.
  3      1.00           3500.             6      4.50             500.

-----------
- GENERAL -
-----------

 MAX TIME STEP (S):          0.000100    PRINT STEP (S):               0.000000    MAX RELATIVE ERROR (-):      0.00200
 PRINT OPTIONS:           1 1 1 0 1 1    STORE OPTION:                        0    CONSTANT-PRESSURE OPTION:          0
 GRADIENT MODEL: LAGRANGIAN

----------
- RECOIL -
----------

 RECOIL OPTION:                      0   TYPE:                                     RECOILING WEIGHT (LB):             0.

----------
- PRIMER -
----------

 TYPE: BLK POWDER                        GAMMA (-):                      1.2500    FORCE (FT-LB/LB):              96000.
 COVOLUME (IN3/LB):             30.000   FLAME TEMP (K):                 2000.0    WEIGHT (LB):                 0.015400
```

- CHARGE 1 -

TYPE: BLACK POWDER		GRAINS:	3487.3	CORD	WEIGHT (LB):	0.3125
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.19800	GRAIN DIAMETER (IN):		0.09800		

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06000	------	------	------	0.06000
GAMMA (-):	------	------	------	1.2500	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	96000.	------	------	------	96000.
COVOLUME (IN3/LB):	------	------	------	30.000	------	------	------	30.000
FLAME TEMP (K):	------	------	------	2000.0	------	------	------	2000.0
BURNING RATE EXPS:	------	------	------	0.0060	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	50.0000000	------	------	------	50.0000000

- CHARGE 2 -

TYPE: NC TUBE		GRAINS:	1.7662	1PF	WEIGHT (LB):	0.3125
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	5.75000	GRAIN DIAMETER (IN):		2.00000	PERF DIAMETER (IN):	1.68750
INNER WEB (IN):	0.15625	WEB RATIO:		1.0000		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.03400	------	------	------	0.03400
GAMMA (-):	------	------	------	1.2500	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	180000.	------	------	------	180000.
COVOLUME (IN3/LB):	------	------	------	30.000	------	------	------	30.000
FLAME TEMP (K):	------	------	------	1553.0	------	------	------	1553.0
BURNING RATE EXPS:	------	------	------	0.0000	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	0.0000100	------	------	------	0.0000100

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.03400
GAMMA (-):	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	180000.
COVOLUME (IN3/LB):	------	------	------	30.000
FLAME TEMP (K):	------	------	------	1553.0
BURNING RATE EXPS:	------	------	------	0.0000
BURNING RATE COEFFS:	------	---	------	0.0000100

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- CHARGE 3 -
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TYPE: NC TUBE		GRAINS: 0.27619E-02 1PF	WEIGHT (LB): 0.0001
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE: 0	CHARGE IGN AT (S): 0.00000E+00
GRAIN LENGTH (IN):	5.75000	GRAIN DIAMETER (IN): 5.90000	PERF DIAMETER (IN): 5.89000
INNER WEB (IN):	0.00500	WEB RATIO: 1.0000	

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.03400	------	------	------	0.03400
GAMMA (-):	------	------	------	1.2500	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	180000.	------	------	------	180000.
COVOLUME (IN3/LB):	------	------	------	30.000	------	------	------	30.000
FLAME TEMP (K):	------	------	------	1553.0	------	------	------	1553.0
BURNING RATE EXPS:	------	------	------	0.0000	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	0.0000100	------	------	------	0.0000100

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.03400
GAMMA (-):	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	180000.
COVOLUME (IN3/LB):	------	------	------	30.000
FLAME TEMP (K):	------	------	------	1553.0
BURNING RATE EXPS:	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	0.0000100

- CHARGE 4 -

TYPE: M9 NAIR		GRAINS:	7007.0 CORD	WEIGHT (LB):	1.5000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	4.00000	GRAIN DIAMETER (IN):	0.03370		

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.06000	------	------	------	0.06000
GAMMA (-):	------	------	------	1.2078	------	------	------	1.2078
FORCE (FT-LB/LB):	------	------	------	392399.	------	------	------	392399.
COVOLUME (IN3/LB):	------	------	------	27.365	------	------	------	27.365
FLAME TEMP (K):	------	------	------	3860.0	------	------	------	3860.0
MEAN PRESSURES (PSI):	------	------	------	1000.0	------	------	------	1000.0
MEAN PRESSURES (PSI):	------	------	------	3000.0	------	------	------	3000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	15000.0	------	------	------	15000.0
BURNING RATES (IN/S):	------	------	------	0.62	------	------	------	0.62
BURNING RATES (IN/S):	------	------	------	1.68	------	------	------	1.68
BURNING RATES (IN/S):	------	------	------	1.90	------	------	------	1.90
BURNING RATES (IN/S):	------	------	------	6.13	------	------	------	6.13

- CHARGE 5 -

TYPE: M30A1		GRAINS:	1518.6	1PF	WEIGHT (LB):	22.5000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	5.50000	GRAIN DIAMETER (IN):		0.25538	PERF DIAMETER (IN):	0.07250
INNER WEB (IN):	0.09144	WEB RATIO:		1.0000		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05720	------	------	------	0.05720
GAMMA (-):	------	------	------	1.2430	------	------	------	1.2430
FORCE (FT-LB/LB):	------	------	------	356400.	------	------	------	356400.
COVOLUME (IN3/LB):	------	------	------	28.500	------	------	------	28.500
FLAME TEMP (K):	------	------	------	3040.0	------	------	------	3040.0
MEAN PRESSURES (PSI):	------	------	------	1000.0	------	------	------	1000.0
MEAN PRESSURES (PSI):	------	------	------	5000.0	------	------	------	5000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	30000.0	------	------	------	30000.0
BURNING RATES (IN/S):	------	------	------	0.40	------	------	------	0.40
BURNING RATES (IN/S):	------	------	------	1.35	------	------	------	1.35
BURNING RATES (IN/S):	------	------	------	2.25	------	------	------	2.25
BURNING RATES (IN/S):	------	------	------	5.56	------	------	------	5.56

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05720
GAMMA (-):	------	------	------	1.2430
FORCE (FT-LB/LB):	------	------	------	356400.
COVOLUME (IN3/LB):	------	------	------	28.500
FLAME TEMP (K):	------	------	------	3040.0
MEAN PRESSURES (PSI):	------	------	------	1000.0
MEAN PRESSURES (PSI):	------	------	------	5000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	30000.0
BURNING RATES (IN/S):	------	------	------	0.40
BURNING RATES (IN/S):	------	------	------	1.35
BURNING RATES (IN/S):	------	------	------	2.25
BURNING RATES (IN/S):	------	------	------	5.56

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4	FRAC BURN 5
0.000	0.00	0.	0.	25.	25.	25.	2000.	0.000	0.000	0.000	0.000	0.000
0.100	0.00	0.	0.	172.	172.	172.	2149.	0.234	0.000	0.000	0.001	0.000
0.149	0.00	0.	0.	250.	250.	250.	2203.	0.334	0.000	0.000	0.002	0.000
SHOT-START PRESSURE ACHIEVED												
0.200	0.00	0.	25.	340.	336.	329.	2258.	0.431	0.000	0.000	0.003	0.000
0.300	0.00	0.	76.	527.	517.	496.	2359.	0.591	0.000	0.000	0.006	0.001
0.400	0.00	1.	132.	733.	715.	679.	2457.	0.720	0.000	0.000	0.011	0.002
0.500	0.00	1.	194.	961.	934.	881.	2550.	0.821	0.000	0.000	0.017	0.002
0.600	0.00	2.	262.	1214.	1178.	1106.	2639.	0.895	0.000	0.000	0.025	0.003
0.700	0.01	3.	336.	1496.	1449.	1357.	2723.	0.947	0.000	0.000	0.034	0.004
0.800	0.01	4.	418.	1810.	1753.	1638.	2801.	0.980	0.000	0.000	0.045	0.006
0.980	0.02	7.	587.	2476.	2395.	2234.	2925.	1.000	0.000	0.000	0.070	0.008
PROPELLANT 1 BURNED OUT												
1.000	0.02	7.	608.	2559.	2476.	2308.	2938.	1.000	0.000	0.000	0.073	0.009
1.100	0.03	9.	720.	3008.	2909.	2711.	2994.	1.000	0.000	0.000	0.090	0.011
1.200	0.05	12.	843.	3512.	3396.	3163.	3041.	1.000	0.000	0.000	0.110	0.013
1.300	0.06	15.	976.	4062.	3928.	3659.	3078.	1.000	0.000	0.000	0.130	0.015
1.400	0.08	18.	1118.	4666.	4512.	4205.	3109.	1.000	0.000	0.000	0.152	0.018
1.500	0.11	22.	1274.	5336.	5161.	4810.	3135.	1.000	0.000	0.000	0.177	0.021
1.600	0.13	26.	1442.	6076.	5877.	5480.	3158.	1.000	0.000	0.000	0.204	0.024
1.700	0.17	31.	1624.	6887.	6664.	6216.	3177.	1.000	0.000	0.000	0.234	0.027
1.800	0.21	37.	1819.	7774.	7523.	7023.	3193.	1.000	0.000	0.000	0.266	0.031
1.900	0.26	43.	2027.	8738.	8459.	7901.	3207.	1.000	0.000	0.000	0.301	0.036
2.000	0.31	50.	2247.	9781.	9471.	8853.	3218.	1.000	0.000	0.000	0.339	0.040
2.100	0.38	58.	2478.	10903.	10562.	9880.	3227.	1.000	0.000	0.000	0.380	0.045
2.200	0.45	66.	2749.	12115.	11737.	10980.	3234.	1.000	0.000	0.000	0.424	0.051
2.300	0.54	75.	3049.	13416.	12996.	12156.	3239.	1.000	0.000	0.000	0.469	0.057
2.400	0.63	86.	3364.	14800.	14337.	13411.	3243.	1.000	0.000	0.000	0.517	0.063
2.500	0.74	97.	3692.	16265.	15757.	14740.	3245.	1.000	0.000	0.000	0.566	0.070
2.600	0.87	109.	4031.	17805.	17250.	16140.	3245.	1.000	0.000	0.000	0.617	0.077
2.700	1.01	123.	4384.	19411.	18807.	17600.	3243.	1.000	0.000	0.000	0.668	0.086
2.800	1.16	138.	4968.	21104.	20420.	19052.	3240.	1.000	0.000	0.000	0.719	0.094
2.900	1.34	155.	5578.	22840.	22072.	20536.	3235.	1.000	0.000	0.000	0.769	0.104
3.000	1.53	174.	6211.	24604.	23749.	22038.	3229.	1.000	0.000	0.000	0.817	0.113
3.100	1.76	195.	6822.	26367.	25428.	23550.	3221.	1.000	0.000	0.000	0.862	0.124
3.200	2.00	218.	7439.	281[illegible]3.	27089.	25040.	3211.	1.000	0.000	0.000	0.903	0.135
3.300	2.28	243.	7942.	29799.	28705.	26519.	3199.	1.000	0.000	0.000	0.938	0.147
3.400	2.59	269.	8402.	31410.	30253.	27939.	3186.	1.000	0.000	0.000	0.967	0.159
3.500	2.92	297.	8838.	32922.	31705.	29272.	3170.	1.000	0.000	0.000	0.987	0.171
3.600	3.30	326.	9241.	34310.	33038.	30493.	3153.	1.000	0.000	0.000	0.998	0.184
3.657	3.53	343.	9451.	35029.	33727.	31125.	3142.	1.000	0.000	0.000	1.000	0.192
PROPELLANT 4 BURNED OUT												
3.700	3.71	356.	9607.	35557.	34234.	31589.	3134.	1.000	0.000	0.000	1.000	0.198
3.800	4.15	388.	9957.	36740.	35369.	32628.	3115.	1.000	0.000	0.000	1.000	0.212
3.900	4.64	420.	10287.	37867.	36450.	33618.	3096.	1.000	0.000	0.000	1.000	0.226
4.000	5.16	454.	10578.	38925.	37469.	34556.	3077.	1.000	0.000	0.000	1.000	0.241
4.100	5.73	488.	10850.	39912.	38419.	35431.	3058.	1.000	0.000	0.000	1.000	0.255
4.200	6.34	524.	11100.	40821.	39293.	36237.	3039.	1.000	0.000	0.000	1.000	0.271
4.300	6.99	560.	11327.	41647.	40087.	36968.	3020.	1.000	0.000	0.000	1.000	0.286
4.400	7.68	597.	11530.	42385.	40797.	37622.	3001.	1.000	0.000	0.000	1.000	0.302
4.500	8.42	634.	11707.	43032.	41420.	38196.	2982.	1.000	0.000	0.000	1.000	0.318
4.600	9.20	672.	11860.	43586.	41953.	38687.	2963.	1.000	0.000	0.000	1.000	0.334
4.700	10.03	710.	11986.	44047.	42397.	39096.	2944.	1.000	0.000	0.000	1.000	0.350
4.800	10.91	749.	12087.	44415.	42751.	39422.	2926.	1.000	0.000	0.000	1.000	0.366
4.900	11.83	788.	12163.	44691.	43016.	39667.	2907.	1.000	0.000	0.000	1.000	0.382

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4	FRAC BURN 5
5.000	12.80	827.	12214.	44878.	43196.	39833.	2889.	1.000	0.000	0.000	1.000	0.399
5.100	13.81	867.	12241.	44979.	43293.	39922.	2870.	1.000	0.000	0.000	1.000	0.415
5.173	14.59	896.	12247.	45000.	43314.	39942.	2857.	1.000	0.000	0.000	1.000	0.427
LOCAL PRESSURE MAX DETECTED												
5.200	14.88	906.	12246.	44997.	43311.	39939.	2852.	1.000	0.000	0.000	1.000	0.432
5.300	15.99	946.	12229.	44938.	43254.	39887.	2834.	1.000	0.000	0.000	1.000	0.448
5.400	17.15	985.	12192.	44806.	43127.	39770.	2817.	1.000	0.000	0.000	1.000	0.465
5.500	18.35	1024.	12137.	44607.	42936.	39593.	2799.	1.000	0.000	0.000	1.000	0.481
5.600	19.61	1063.	12064.	44345.	42684.	39362.	2782.	1.000	0.000	0.000	1.000	0.498
5.700	20.91	1102.	11976.	44027.	42378.	39080.	2765.	1.000	0.000	0.000	1.000	0.514
5.800	22.25	1140.	11874.	43658.	42024.	38754.	2748.	1.000	0.000	0.000	1.000	0.530
5.900	23.64	1178.	11760.	43244.	41625.	30387.	2732.	1.000	0.000	0.000	1.000	0.546
6.000	25.08	1216.	11634.	42790.	41188.	37984.	2716.	1.000	0.000	0.000	1.000	0.562
6.100	26.56	1253.	11499.	42300.	40717.	37551.	2700.	1.000	0.000	0.000	1.000	0.577
6.200	28.09	1290.	11355.	41781.	40217.	37091.	2684.	1.000	0.000	0.000	1.000	0.593
6.300	29.66	1326.	11204.	41236.	39693.	36608.	2669.	1.000	0.000	0.000	1.000	0.608
6.400	31.27	1362.	11048.	40669.	39148.	36106.	2654.	1.000	0.000	0.000	1.000	0.623
6.500	32.92	1398.	10886.	40085.	38586.	35588.	2640.	1.000	0.000	0.000	1.000	0.638
6.600	34.62	1432.	10721.	39487.	38010.	35058.	2625.	1.000	0.000	0.000	1.000	0.653
6.700	36.36	1467.	10553.	38878.	37425.	34519.	2611.	1.000	0.000	0.000	1.000	0.668
6.800	38.14	1500.	10383.	38262.	36832.	33973.	2597.	1.000	0.000	0.000	1.000	0.682
6.900	39.96	1533.	10211.	37640.	36234.	33423.	2584.	1.000	0.000	0.000	1.000	0.696
7.000	41.82	1566.	10039.	37017.	35634.	32870.	2571.	1.000	0.000	0.000	1.000	0.710
7.100	43.72	1598.	9866.	36392.	35034.	32317.	2558.	1.000	0.000	0.000	1.000	0.724
7.200	45.66	1630.	9694.	35770.	34435.	31765.	2545.	1.000	0.000	0.000	1.000	0.738
7.300	47.63	1660.	9523.	35150.	33839.	31217.	2533.	1.000	0.000	0.000	1.000	0.751
7.400	49.64	1691.	9353.	34535.	33247.	30672.	2521.	1.000	0.000	0.000	1.000	0.764
7.500	51.69	1721.	9185.	33926.	32661.	30132.	2509.	1.000	0.000	0.000	1.000	0.777
7.600	53.77	1750.	9018.	33323.	32082.	29598.	2497.	1.000	0.000	0.000	1.000	0.790
7.700	55.89	1779.	8854.	32729.	31510.	29071.	2486.	1.000	0.000	0.000	1.000	0.803
7.800	58.04	1807.	8692.	32143.	30946.	28552.	2475.	1.000	0.000	0.000	1.000	0.815
7.900	60.23	1835.	8533.	31566.	30391.	28041.	2464.	1.000	0.000	0.000	1.000	0.828
8.000	62.44	1862.	8376.	30998.	29845.	27539.	2453.	1.000	0.000	0.000	1.000	0.840
8.100	64.69	1889.	8222.	30441.	29309.	27045.	2443.	1.000	0.000	0.000	1.000	0.852
8.200	66.98	1915.	8071.	29895.	28783.	26561.	2433.	1.000	0.000	0.000	1.000	0.863
8.300	69.29	1941.	7923.	29358.	28268.	26086.	2423.	1.000	0.000	0.000	1.000	0.875
8.400	71.63	1966.	7778.	28833.	27762.	25621.	2413.	1.000	0.000	0.000	1.000	0.886
8.500	74.01	1991.	7635.	28319.	27267.	25165.	2404.	1.000	0.000	0.000	1.000	0.897
8.600	76.41	2015.	7496.	27815.	26783.	24719.	2394.	1.000	0.000	0.000	1.000	0.908
8.700	78.84	2039.	7360.	27323.	26310.	24283.	2385.	1.000	0.000	0.000	1.000	0.919
8.800	81.31	2063.	7227.	26842.	25847.	23856.	2376.	1.000	0.000	0.000	1.000	0.930
8.900	83.79	2086.	7097.	26371.	25394.	23440.	2367.	1.000	0.000	0.000	1.000	0.940
9.000	86.31	2108.	6970.	25911.	24952.	23032.	2358.	1.000	0.000	0.000	1.000	0.951
9.100	88.85	2131.	6846.	25462.	24520.	22635.	2350.	1.000	0.000	0.000	1.000	0.961
9.200	91.42	2152.	6725.	25024.	24098.	22246.	2342.	1.000	0.000	0.000	1.000	0.971
9.300	94.02	2174.	6606.	24596.	23686.	21867.	2333.	1.000	0.000	0.000	1.000	0.981
9.400	96.64	2195.	6491.	24178.	23284.	21497.	2325.	1.000	0.000	0.000	1.000	0.991
9.496	99.18	2215.	6371.	23746.	22869.	21114.	2317.	1.000	0.000	0.000	1.000	1.000
PROPELLANT 5 BURNED OUT												
9.500	99.29	2216.	6363.	23717.	22841.	21089.	2316.	1.000	0.000	0.000	1.000	1.000
9.600	101.96	2236.	6175.	23034.	22184.	20484.	2302.	1.000	0.000	0.000	1.000	1.000
9.700	104.65	2255.	5994.	22380.	21555.	19904.	2288.	1.000	0.000	0.000	1.000	1.000
9.800	107.37	2274.	5821.	21753.	20952.	19349.	2275.	1.000	0.000	0.000	1.000	1.000
9.900	110.11	2293.	5655.	21152.	20373.	18816.	2262.	1.000	0.000	0.000	1.000	1.000
10.000	112.87	2311.	5496.	20575.	19819.	18305.	2249.	1.000	0.000	0.000	1.000	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4	FRAC BURN 5
10.100	115.66	2328.	5343.	20022.	19287.	17815.	2236.	1.000	0.000	0.000	1.000	1.000
10.200	118.46	2345.	5196.	19491.	18776.	17365.	2223.	1.000	0.000	0.000	1.000	1.000
10.300	121.28	2362.	5056.	18982.	18285.	16893.	2211.	1.000	0.000	0.000	1.000	1.000
10.400	124.13	2378.	4920.	18492.	17814.	16459.	2199.	1.000	0.000	0.000	1.000	1.000
10.500	126.99	2393.	4790.	18021.	17361.	16042.	2187.	1.000	0.000	0.000	1.000	1.000
10.600	129.87	2409.	4665.	17568.	16926.	15641.	2176.	1.000	0.000	0.000	1.000	1.000
10.700	132.77	2424.	4545.	17133.	16507.	15255.	2164.	1.000	0.000	0.000	1.000	1.000
10.800	135.69	2438.	4429.	16714.	16104.	14884.	2153.	1.000	0.000	0.000	1.000	1.000
10.900	138.62	2452.	4318.	16310.	15716.	14527.	2142.	1.000	0.000	0.000	1.000	1.000
11.000	141.57	2466.	4210.	15921.	15342.	14182.	2131.	1.000	0.000	0.000	1.000	1.000
11.100	144.54	2479.	4107.	15547.	14981.	13850.	2121.	1.000	0.000	0.000	1.000	1.000
11.200	147.52	2492.	4007.	15186.	14634.	13531.	2110.	1.000	0.000	0.000	1.000	1.000
11.300	150.52	2505.	3911.	14838.	14299.	13222.	2100.	1.000	0.000	0.000	1.000	1.000
11.400	153.53	2517.	3818.	14502.	13976.	12925.	2090.	1.000	0.000	0.000	1.000	1.000
11.500	156.56	2530.	3728.	14178.	13664.	12638.	2080.	1.000	0.000	0.000	1.000	1.000
11.600	159.61	2541.	3642.	13865.	13363.	12360.	2070.	1.000	0.000	0.000	1.000	1.000
11.700	162.66	2553.	3558.	13562.	13072.	12093.	2060.	1.000	0.000	0.000	1.000	1.000
11.800	165.73	2564.	3478.	13270.	12791.	11834.	2051.	1.000	0.000	0.000	1.000	1.000
11.900	168.82	2575.	3400.	12988.	12520.	11584.	2042.	1.000	0.000	0.000	1.000	1.000
12.000	171.91	2586.	3324.	12715.	12257.	11342.	2032.	1.000	0.000	0.000	1.000	1.000
12.100	175.02	2597.	3251.	12451.	12003.	11103.	2023.	1.000	0.000	0.000	1.000	1.000
12.200	178.15	2607.	3180.	12195.	11758.	10882.	2015.	1.000	0.000	0.000	1.000	1.000
12.300	181.28	2617.	3112.	11948.	11520.	10663.	2006.	1.000	0.000	0.000	1.000	1.000
12.400	184.43	2627.	3046.	11709.	11289.	10451.	1997.	1.000	0.000	0.000	1.000	1.000
12.500	187.59	2637.	2982.	11477.	11066.	10245.	1989.	1.000	0.000	0.000	1.000	1.000
12.600	190.76	2646.	2920.	11252.	10850.	10046.	1980.	1.000	0.000	0.000	1.000	1.000
12.700	193.94	2656.	2859.	11034.	10640.	9853.	1972.	1.000	0.000	0.000	1.000	1.000
12.800	197.13	2665.	2801.	10823.	10437.	9666.	1964.	1.000	0.000	0.000	1.000	1.000
12.900	200.33	2674.	2744.	10618.	10240.	9484.	1956.	1.000	0.000	0.000	1.000	1.000
13.000	203.55	2683.	2689.	10419.	10049.	9308.	1948.	1.000	0.000	0.000	1.000	1.000
13.045	205.00	2666.	2665.	10331.	9964.	9231.	1945.	1.000	0.000	0.000	1.000	1.000

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	5.173	13.045
TRAVEL (IN):	14.59	205.00
VELOCITY (FT/S)	896.	2686.
ACCELERATION (G):	12247.	2665.
BREECH PRESS (PSI):	65000.	10331.
MEAN PRESS (PSI):	43314.	9964.
BASE PRESS (PSI):	39942.	9231.
MEAN TEMP (K):	2857.	1945.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.000	0.000
Z CHARGE 3 (-):	0.000	0.000
Z CHARGE 4 (-):	1.000	1.000
Z CHARGE 5 (-):	0.427	1.000

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	431019520.	100.00
(1) INTERNAL GAS:	271604224.	63.01
(2) WORK AND LOSSES:	159415408.	36.99
(A) PROJECTILE KINETIC:	129095072.	29.95
(B) GAS KINETIC:	11045006.	2.56
(C) PROJECTILE ROTATIONAL:	1592645.	0.37
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	3175198.	0.74
(F) WORK DONE AGAINST AIR:	612820.	0.14
(G) HEAT CONVECTED TO BORE:	13894672.	3.22
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3): 0.593
CHARGE WT/PROJECTILE WT: 0.257
PIEZOMETRIC EFFICIENCY: 0.469
EXPANSION RATIO: 6.317

Test Case 5

This is another another example of deterred propellant grains for the second $PROP deck. A transition zone of 0.001 thickness is added to gain a smooth transition from the outer shell to the inner propellant. An obvious correction by the program is shown where the second propellant grain diameter is input as five inches, then corrected to 0.4837 in the form function subroutine when the web distances and perforation diameters are added.

Using the $FIND deck, the program is directed to search for a solution where peak breech pressure is 63000 *psi* and muzzle velocity of the projectile is maximized. The searching method employed is a function minimization routine developed at BRL many years ago, and will be replaced by another technique in the future. The current code does find solutions when possible, but actual 'best case' may elude the algorithm. In the run output, a table of trial values follows the input card echoes where each line represents a full ballistic calculation by IBHVG2.

```
$COMM
  IBHVG2 BENCHMARK TEST CASE 5

  SHOW DETERRED PROPELLANT EXAMPLE
  USE 'FIND' FUNCTION TO SEARCH FOR SPECIFIC SOLUTION

$HEAT
      TSHL = 0.00450        CSHL = 1848        RSHL = 0.284
      TWAL = 293            HO   = 0.0648      HL   = 1

$GUN
      NAME = '  120MM GUN'    CHAM = 525        GRVE = 4.724
      LAND = 4.724          G/L  = 1.      TRAV = 187.11
      TWST = 99

$PROJ
      NAME = 'APFSDS'    PRWT = 21.1

$RESI
      NPTS = 4              AIR  = 1
      TRAV =       0,    0.8,      3.0,     187
      PRES =     100,   2500,    100,     100

$INFO
      RUN  = ' 120 MM GUN DETERRED-120DET'   DELT = 5E-5        DELP = 5E-5
      GRAD = 2              POPT = 1,1,1,0,2   SOPT = 0
      EPS  = 0.05           COMP = 0

$RECO
      NAME = 'NONE'         RECO = 0           RCWT = 0

$PRIM
      NAME = 'BENITE'       CHWT = 0.00347
      GAMA = 1.25        FORC = 212500
      COV  = 30             TEMP = 2000
$PROP
      NAME = 'BENITE'       CHWT = 0.06653   GRAN = 'CORD'
      RHO  = 0.06         GAMA = 1.25      FORC = 212500
      COV  = 30             TEMP = 2000       EROS = 0.00000
      ALPH = 0              BETA = 27         IGNC = 0
      LEN  = 9.998         DIAM = 0.078

$COMM
    VARY WEB AND CHARGE WEIGHT OF SECOND PROPELLANT TO FIND
      A SOLUTION AT APPROX 63KPSI AND MAXIMUM MUZZLE VELOCITY
$FIND
    VARY='WEB'  FROM=.070   VAL=63000  NTH=2  OUTV='PMAX'   CODE=0
    MIN=0.063   DECK='PROP'    EPS=0.0001
$FIND
```

```
    VARY='CHWT' DECK='PROP' NTH=2   FROM=20.0  EPS=0.01  OUTV='VMUZ'
    CODE=1   MULT=0.5    MIN=18.    MAX=22.

$COMM
    OUTER LAYER HAS LOW BURNING RATE (DETERRED), NEXT LAYER IS A THIN
    TRANSITION ZONE, AND CORE LAYER (4) IS THE MAIN PROPELLANT
$PROP
    NAME = 'JA2-G54  0.85-0.15  19P'     CHWT = 20.5       GRAN = '19PF'
    RHO=0.05732      EROS = 0.0000000
    LEN  = 3         DIAM = 5       PD    = 0.020    WEB=0.0625

    GAMP=,1.2725,1.2725,1.2257    GAME=,1.2725,1.2725,1.2257
    GAML=,1.2725,1.2725,1.2257

    COVP=,31.17,31.17,27.48       COVE=,31.17,31.17,27.48
    COVL=,31.17,31.17,27.48

    TMPL=,2248,2248,3400  TMPE=,2248,2248,3400  TMPP=,2248,2248,3400

    FRCL=,300417,300417,382152  FRCE=,300417,300417,382152
    FRCP=,300417,300417,382152

    DEPP=,0.03,0.031    DEPE=,0.03,0.031    DEPL=,0.03,0.031

    NTBL=4  PR4L=2000,4000,10000,25000
    BR4L=1.05,1.52,2.93,6.56
    PR3L=2000,4000,10000,25000 PR2L=2000,4000,10000,25000
    BR3L=0.694,1.01,1.94,4.34   BR2L=0.694,1.01,1.94,4.34
    PR4P=2000,4000,10000,25000  BR4P=1.05,1.52,2.93, 6.56
    PR3P=2000,4000,10000,25000  BR3P=0.694,1.01,1.94,4.34
    PR2P=2000,4000,10000,25000  BR2P=0.694,1.01,1.94,4.34
    PR4E=2000,4000,10000,25000  BR4E=1.05,1.52,2.93,6.56
    PR3E=2000,4000,10000,25000  BR3E=0.694,1.01,1.94,4.34
    PR2E=2000,4000,10000,25000  BR2E=0.694,1.01,1.94,4.34

$COMM
   THIRD AND FOURTH PROPELLANTS MAKE UP A COMBUSTIBLE CARTRIDGE CASE
     OF FELTED NITRO-CELLULOSE AND KRAFT PAPER
$PROP
    NAME = 'FNC CASE'     CHWT = 1.41        GRAN = '1PF'
    RHO  = 0.04         GAMA = 1.258
    FRCP= ,150000,150000  FRCE= ,150000,150000 FRCL(4)=200000
    COV  = 27.927          TEMP = 1610          EROS = 0.00
    IGNS(3)=2   THRS(3)=200    DEPP= , 0.015 , 0.0155   DEPE= , 0.015 , 0.0155
    NTBL=2
    PR2P=1000,10000  BR2P=0.5,2.4      PR3P=1000,10000  BR3P=0.5,2.4
    PR2E=1000,10000  BR2E=0.5,2.4      PR3E=1000,10000  BR3E=0.5,2.4
    PR4L=1000,10000  BR4L=0.5,10
    LEN  =  18         DIAM = 6.17      PD    = 6.01
    WI  =   0.08
$PROP
      NAME = 'KRAFT CASE'     CHWT = .21       GRAN = '1PF'
      RHO  = 0.04         GAMA = 1.2734       FORC = 95726
      COV  = 9.883          TEMP = 1054       EROS = 0.00
      ALPH =  1            BETA = 0.00001  IGNC = 0
      LEN  = 3.4         DIAM = 6.17      PD    = 6.01
      WI  =   0.08
$END
```

Producing the following output:

```
ERRTOL=   4.768372E-07

CARD   1 --> $COMM
CARD   2 -->     IBHVG2 BENCHMARK TEST CASE 5
CARD   3 -->
CARD   4 -->     SHOW DETERRED PROPELLANT EXAMPLE
CARD   5 -->     USE 'FIND' FUNCTION TO SEARCH FOR SPECIFIC SOLUTION
CARD   6 -->
CARD   7 --> $HEAT
CARD   8 -->          TSHL = 0.00450        CSHL = 1848       RSHL = 0.284
CARD   9 -->          TWAL = 293            HO   = 0.0648     HL   = 1
CARD  10 -->
CARD  11 --> $GUN
CARD  12 -->          NAME = '  120MM GUN'    CHAM = 525        GRVE = 4.724
CARD  13 -->          LAND = 4.724          G/L  = 1.        TRAV = 187.11
CARD  14 -->          TWST = 99
CARD  15 -->
CARD  16 --> $PROJ
CARD  17 -->          NAME = 'APFSDS'    PRWT = 21.1
CARD  18 -->
CARD  19 --> $RESI
CARD  20 -->          NPTS = 4              AIR  = 1
CARD  21 -->          TRAV =       0,    0.8,       3.0,      187
CARD  22 -->          PRES =     100,   2500,   100,    100
CARD  23 -->
CARD  24 --> $INFO
CARD  25 -->          RUN  = ' 120 MM GUN DETERRED-120DET'   DELT = 5E-5       DELP = 5E-5
CARD  26 -->          GRAD = 2              POPT = 1,1,1,0,2    SOPT = 0
CARD  27 -->          EPS  = 0.05           COMP = 0
CARD  28 -->
CARD  29 --> $RECO
CARD  30 -->          NAME = 'NONE'         RECO = 0          RCWT = 0
CARD  31 -->
CARD  32 --> $PRIM
CARD  33 -->          NAME = 'BENITE'       CHWT = 0.00347
CARD  34 -->          GAMA = 1.25         FORC = 212500
CARD  35 -->          COV  = 30             TEMP = 2000
CARD  36 --> $PROP
CARD  37 -->          NAME = 'BENITE'       CHWT = 0.06653   GRAN = 'CORD'
CARD  38 -->          RHO  = 0.06         GAMA = 1.25       FORC = 212500
CARD  39 -->          COV  = 30             TEMP = 2000       EROS = 0.00000
CARD  40 -->          ALPH = 0              BETA = 27         IGNC = 0
CARD  41 -->          LEN  = 9.998         DIAM = 0.078
CARD  42 -->
CARD  43 --> $COMM
CARD  44 -->       VARY WEB AND CHARGE WEIGHT OF SECOND PROPELLANT TO FIND
CARD  45 -->          A SOLUTION AT APPROX 63KPSI AND MAXIMUM MUZZLE VELOCITY
CARD  46 --> $FIND
CARD  47 -->         VARY='WEB'  FROM=.070   VAL=63000  NTH=2  OUTV='PMAX'    CODE=0
CARD  48 -->         MIN=0.063   DECK='PROP'    EPS=0.0001
CARD  49 --> $FIND
CARD  50 -->         VARY='CHWT' DECK='PROP' NTH=2    FROM=20.0  EPS=0.01  OUTV='VMUZ'
CARD  51 -->         CODE=1   MULT=0.5    MIN=18.     MAX=22.
CARD  52 -->
CARD  53 --> $COMM
CARD  54 -->       OUTER LAYER HAS LOW BURNING RATE (DETERRED), NEXT LAYER IS A THIN
CARD  55 -->       TRANSITION ZONE, AND CORE LAYER (4) IS THE MAIN PROPELLANT
```

```
CARD  56 --> $PROP
CARD  57 -->     NAME = 'JA2-G54  .85-.15  19P'     CHWT = 20.5      GRAN = '19PF'
CARD  58 -->     RHO=0.05732    EROS = 0.0000000
CARD  59 -->     LEN  = 3       DIAM = 5       PD   = 0.020   WEB=0.0625
CARD  60 -->
CARD  61 -->     GAMP=,1.2725,1.2725,1.2257   GAME=,1.2725,1.2725,1.2257
CARD  62 -->     GAML=,1.2725,1.2725,1.2257
CARD  63 -->
CARD  64 -->     COVP=,31.17,31.17,27.48       COVE=,31.17,31.17,27.48
CARD  65 -->     COVL=,31.17,31.17,27.48
CARD  66 -->
CARD  67 -->     TMPL=,2248,2248,3400  TMPE=,2248,2248,3400  TMPP=,2248,2248,3400
CARD  68 -->
CARD  69 -->     FRCL=,300417,300417,382152  FRCE=,300417,300417,382152
CARD  70 -->     FRCP=,300417,300417,382152
CARD  71 -->
CARD  72 -->     DEPP=,0.03,0.031    DEPE=,0.03,0.031    DEPL=,0.03,0.031
CARD  73 -->
CARD  74 -->     NTBL=4  PR4L=2000,4000,10000,25000
CARD  75 -->     BR4L=1.05,1.52,2.93,6.56
CARD  76 -->     PR3L=2000,4000,10000,25000 PR2L=2000,4000,10000,25000
CARD  77 -->     BR3L=0.694,1.01,1.94,4.34   BR2L=0.694,1.01,1.94,4.34
CARD  78 -->     PR4P=2000,4000,10000,25000  BR4P=1.05,1.52,2.93, 6.56
CARD  79 -->     PR3P=2000,4000,10000,25000  BR3P=0.694,1.01,1.94,4.34
CARD  80 -->     PR2P=2000,4000,10000,25000  BR2P=0.694,1.01,1.94,4.34
CARD  81 -->     PR4E=2000,4000,10000,25000  BR4E=1.05,1.52,2.93,6.56
CARD  82 -->     PR3E=2000,4000,10000,25000  BR3E=0.694,1.01,1.94,4.34
CARD  83 -->     PR2E=2000,4000,10000,25000  BR2E=0.694,1.01,1.94,4.34
CARD  84 -->
CARD  85 --> $COMM
CARD  86 -->    THIRD AND FOURTH PROPELLANTS MAKE UP A COMBUSTIBLE CARTRIDGE CASE
CARD  87 -->      OF FELTED NITRO-CELLULOSE AND KRAFT PAPER
CARD  88 --> $PROP
CARD  89 -->     NAME = 'FNC CASE'     CHWT = 1.41      GRAN = '1PF'
CARD  90 -->     RHO  = 0.04         GAMA = 1.258
CARD  91 -->     FRCP= ,150000,150000  FRCE= ,150000,150000 FRCL(4)=200000
CARD  92 -->     COV  = 27.927          TEMP = 1610       EROS = 0.00
CARD  93 -->     IGNS(3)=2   THRS(3)=200    DEPP= , 0.015 , 0.0155   DEPE= , 0.015 , 0.0155
CARD  94 -->     NTBL=2
CARD  95 -->     PR2P=1000,10000  BR2P=0.5,2.4    PR3P=1000,10000  BR3P=0.5,2.4
CARD  96 -->     PR2E=1000,10000  BR2E=0.5,2.4    PR3E=1000,10000  BR3E=0.5,2.4
CARD  97 -->     PR4L=1000,10000  BR4L=0.5,10
CARD  98 -->     LEN  =  18         DIAM = 6.17     PD   = 6.01
CARD  99 -->     WI =   0.08
CARD 100 --> $PROP
CARD 101 -->        NAME = 'KRAFT CASE'     CHWT = .21      GRAN = '1PF'
CARD 102 -->        RHO  = 0.04         GAMA = 1.2734      FORC = 95726
CARD 103 -->        COV  = 9.883          TEMP = 1054      EROS = 0.0
CARD 104 -->        ALPH =  1          BETA = 0.00001  IGNC = 0
CARD 105 -->        LEN  = 3.4       DIAM = 6.17     PD   = 6.01
CARD 106 -->        WI =   0.03
CARD 107 --> $END
```

VARY / 1/ WEB 2 PROP TO HIT < 1> PMAX = 0.6300E+05
VARY / 2/ CHWT 2 PROP TO MAX < 2> VMUZ

/ 1/	< 1>	/ 2/	< 2>
0.7000E-01	0.4430E+05	20.00	3520.
0.7011E-01	0.4414E+05	20.00	3513.
0.6989E-01	0.4445E+05	20.00	3528.
0.6945E-01	0.4508E+05	20.00	3555.
0.6945E-01	0.4519E+05	20.01	3561.
0.6945E-01	0.4530E+05	20.02	3564.
0.6945E-01	0.4562E+05	20.05	3573.
0.6890E-01	0.4701E+05	20.11	3627.
0.6395E-01	0.6323E+05	20.60	4224.
0.6395E-01	0.6412E+05	20.66	4019.
0.6395E-01	0.6236E+05	20.55	4202.
0.6395E-01	0.6299E+05	20.59	4217.
0.6340E-01	0.6533E+05	20.64	4287.
0.6450E-01	0.6078E+05	20.53	615[illegible].
0.6395E-01	0.6275E+05	20.57	4214.
0.6395E-01	0.6323E+05	20.60	4224.
0.6395E-01	0.6275E+05	20.57	4214.
0.6385E-01	0.6341E+05	20.60	4231.
0.6405E-01	0.6258E+05	20.58	4201.

```
------------
- GUN TUBE -
------------

 TYPE: 120MM GUN                              CHAMBER VOLUME (IN3):          525.00     TRAVEL (IN):                  187.11
 GROOVE DIAMETER (IN):            4.724       LAND DIAMETER (IN):             4.724     GROOVE/LAND RATIO (-):         1.000
 TWIST (CALS/TURN):                99.0       BORE AREA (IN2):               17.5271    HEAT-LOSS OPTION:                  1
 SHELL THICKNESS (IN):         0.004500       SHELL CP (IN-LB/LB-K):         1848.0     SHELL DENSITY (LB/IN3):       0.2840
 INITIAL SHELL TEMP (K):           293.       AIR HO (IN-LB/IN2-S-K):       0.06480

--------------
- PROJECTILE -
--------------

 TYPE: APFSDS                                 TOTAL WEIGHT (LB):             21.100     WEIGHT PREDICTOR OPTION:           0

--------------
- RESISTANCE -
--------------

 AIR RESISTANCE OPTION:               1       WALL HEATING FRACTION:          0.000     FRICTION TABLE LENGTH:             4

 I   TRAVEL (IN)     PRESSURE (PSI)           I   TRAVEL (IN)     PRESSURE (PSI)        I   TRAVEL (IN)     PRESSURE (PSI)

 1       0.00             100.                3       3.00             100.             4     187.00             100.
 2       0.80            2500.

-----------
- GENERAL -
-----------

 MAX TIME STEP (S):            0.000050       PRINT STEP (S):              0.000050     MAX RELATIVE ERROR (-):      0.05000
 PRINT OPTIONS:             1 1 1 0 2 1       STORE OPTION:                       0     CONSTANT-PRESSURE OPTION:          0
 GRADIENT MODEL: PIDDUCK-KENT

----------
- RECOIL -
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 RECOIL OPTION:                       0       TYPE: NONE                                RECOILING WEIGHT (LB):            0.

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- PRIMER -
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 TYPE: BENITE                                 GAMMA (-):                     1.2500     FORCE (FT-LB/LB):            212500.
 COVOLUME (IN3/LB):              30.000       FLAME TEMP (K):                2000.0     WEIGHT (LB):                0.003470
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- CHARGE 1 -
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TYPE: BENITE		GRAINS:	23.210	CORD		WEIGHT (LB):	0.0665
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0		CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	9.99800	GRAIN DIAMETER (IN):		0.07800			

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES				PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	[illegible]	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	[illegible]	------	------	------	0.06000
GAMMA (-):	------	------	------	[illegible]	------	------	------	1.2500
FORCE (FT-LB/LB):	------	------	------	[illegible]	------	------	------	212500.
COVOLUME (IN3/LB):	------	------	------	[illegible]	------	------	------	30.000
FLAME TEMP (K):	------	------	------	[illegible]	------	------	------	2000.0
BURNING RATE EXPS:	------	------	------	0.0000	------	------	------	0.0000
BURNING RATE COEFFS:	------	------	------	27.0000000	------	------	------	27.0000000

- CHARGE 2 -

TYPE: JA2-G54 .85-.15 19P		GRAINS: 673.47	19PF	WEIGHT (LB):	20.5897
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	3.00000	GRAIN DIAMETER (IN):	0.48370	PERF DIAMETER (IN):	0.02000
INNER WEB (IN):	0.06395	MIDDLE WEB (IN):	0.06395	OUTER WEB (IN):	0.06395

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	0.00000	0.03000	0.03100
ADJACENT LAYER WT %:	------	49.756	2.664	21.665
DENSITY (LB/IN3):	------	0.05732	0.05732	0.05732
GAMMA (-):	------	1.2725	1.2725	1.2257
FORCE (FT-LB/LB):	------	300417.	300417.	382152.
COVOLUME (IN3/LB):	------	31.170	31.170	27.480
FLAME TEMP (K):	------	224[illegible]	2248.0	3400.0
MEAN PRESSURES (PSI):	------	2000.0	2000.0	2000.0
MEAN PRESSURES (PSI):	------	4000.0	4000.0	4000.0
MEAN PRESSURES (PSI):	------	10000.0	10000.0	10000.0
MEAN PRESSURES (PSI):	------	25000.0	25000.0	25000.0
BURNING RATES (IN/S):	------	0.69	0.69	1.05
BURNING RATES (IN/S):	------	1.01	1.01	1.52
BURNING RATES (IN/S):	------	1.94	1.94	2.93
BURNING RATES (IN/S):	------	4.34	4.34	6.56

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	0.00000	0.03000	0.03100
ADJACENT LAYER WT %:	------	1.351	0.016	21.665
DENSITY (LB/IN3):	------	0.05732	0.05732	0.05732
GAMMA (-):	------	1.2725	1.2725	1.2257
FORCE (FT-LB/LB):	------	300417.	300417.	382152.
COVOLUME (IN3/LB):	------	31.170	31.170	27.480
FLAME TEMP (K):	------	2248.0	2248.0	3400.0
MEAN PRESSURES (PSI):	------	2000.0	2000.0	2000.0
MEAN PRESSURES (PSI):	------	4000.0	4000.0	4000.0
MEAN PRESSURES (PSI):	------	10000.0	10000.0	10000.0
MEAN PRESSURES (PSI):	------	25000.0	25000.0	25000.0
BURNING RATES (IN/S):	------	0.69	0.69	1.05
BURNING RATES (IN/S):	------	1.01	1.01	1.52
BURNING RATES (IN/S):	------	1.94	1.94	2.93
BURNING RATES (IN/S):	------	4.34	4.34	6.56

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	0.00000	0.03000	0.03100
ADJACENT LAYER WT %:	------	23.816	0.732	21.665
DENSITY (LB/IN3):	------	0.05732	0.05732	0.05732
GAMMA (-):	------	1.2725	1.2725	1.2257
FORCE (FT-LB/LB):	------	300417.	300417.	382152.
COVOLUME (IN3/LB):	------	31.170	31.170	27.480
FLAME TEMP (K):	------	2248.0	2248.0	3400.0
MEAN PRESSURES (PSI):	------	2000.0	2000.0	2000.0
MEAN PRESSURES (PSI):	------	4000.0	4000.0	4000.0
MEAN PRESSURES (PSI):	------	10000.0	10000.0	10000.0
MEAN PRESSURES (PSI):	------	25000.0	25000.0	25000.0
BURNING RATES (IN/S):	------	0.69	0.69	1.05
BURNING RATES (IN/S):	------	1.01	1.01	1.52
BURNING RATES (IN/S):	------	1.94	1.94	2.93
BURNING RATES (IN/S):	------	4.34	4.34	6.56

- CHARGE 3 -

TYPE: FNC CASE		GRAINS:	1.2795	1PF	WEIGHT (LB):	1.4100
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0		CHARGE IGN AT (S):	0.00000E+00
P-SURFACE IGN CODE:	0	E-SURFACE IGN CODE:	0		L-SURFACE IGN CODE:	2
P-SURF IGN AT (S):	0.00000E+00	E-SURF IGN AT (S):	0.00000E+00		L-SURF IGN AT (IN):	0.20000E+03
GRAIN LENGTH (IN):	18.00000	GRAIN DIAMETER (IN):	6.17000		PERF DIAMETER (IN):	6.01000
INNER WEB (IN):	0.08000	WEB RATIO:	1.0000			

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	0.00000	0.01500	0.01550	------	0.00000	0.01500	0.01550
ADJACENT LAYER WT %:	------	18.535	0.618	80.690	------	0.151	0.005	80.690
DENSITY (LB/IN3):	------	0.04000	0.04000	0.04000	------	0.04000	0.04000	0.04000
GAMMA (-):	------	1.2580	1.2580	1.2580	------	1.2580	1.2580	1.2580
FORCE (FT-LB/LB):	------	150000.	150000.	200000.	------	150000.	150000.	200000.
COVOLUME (IN3/LB):	------	27.927	27.927	27.927	------	27.927	27.927	27.927
FLAME TEMP (K):	------	1610.0	1610.0	1610.0	------	1610.0	1610.0	1610.0
MEAN PRESSURES (PSI):	------	1000.0	1000.0	1000.0	------	1000.0	1000.0	1000.0
MEAN PRESSURES (PSI):	------	10000.0	10000.0	10000.0	------	10000.0	10000.0	10000.0
BURNING RATES (IN/S):	------	0.50	0.50	0.50	------	0.50	0.50	0.50
BURNING RATES (IN/S):	------	2.40	2.40	10.00	------	2.40	2.40	10.00

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	80.690
DENSITY (LB/IN3):	------	------	------	0.04000
GAMMA (-):	------	------	------	1.2580
FORCE (FT-LB/LB):	------	------	------	200000.
COVOLUME (IN3/LB):	------	------	------	27.927
FLAME TEMP (K):	------	------	------	1610.0
MEAN PRESSURES (PSI):	------	------	------	1000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
BURNING RATES (IN/S):	------	------	------	0.50
BURNING RATES (IN/S):	------	------	------	10.00

- CHARGE 4 -

TYPE: KRAFT CASE		GRAINS:	1.0088	1PF	WEIGHT (LB):	0.2100
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:		0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	3.40000	GRAIN DIAMETER (IN):		6.17000	PERF DIAMETER (IN):	6.01000
INNER WEB (IN):	0.08000	WEB RATIO:		1.0000		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES				PROPERTIES AT LAYER BOUNDARIES OF END SURFACES			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.04000	------	------	------	0.04000
GAMMA (-):	------	------	------	1.2734	------	------	------	1.2734
FORCE (FT-LB/LB):	------	------	------	95726.	------	------	------	95726.
COVOLUME (IN3/LB):	------	------	------	9.883	------	------	------	9.883
FLAME TEMP (K):	------	------	------	1054.0	------	------	------	1054.0
BURNING RATE EXPS:	------	------	------	1.0000	------	------	------	1.0000
BURNING RATE COEFFS:	------	------	------	0.0000100	------	------	------	0.0000100

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			
	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.04000
GAMMA (-):	------	------	------	1.2734
FORCE (FT-LB/LB):	------	------	------	95726.
COVOLUME (IN3/LB):	------	------	------	9.883
FLAME TEMP (K):	------	------	------	1054.0
BURNING RATE EXPS:	------	------	------	1.0000
BURNING RATE COEFFS:	------	------	------	0.0000100

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	[illegible] (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4
0.000	0.00	0.	0.	71.	71.	71.	2000.	0.000	0.000	0.000	0.000
0.010	0.00	0.	0.	101.	101.	101.	2023.	0.013	0.000	0.000	0.000
SHOT-START PRESSURE ACHIEVED											
0.050	0.00	0.	73.	281.	248.	187.	2067.	0.068	0.000	0.000	0.000
0.100	0.00	0.	212.	533.	470.	355.	2093.	0.134	0.000	0.000	0.000
0.150	0.00	1.	377.	832.	734.	555.	2110.	0.198	0.001	0.000	0.000
0.200	0.00	1.	565.	1176.	1037.	784.	2122.	0.259	0.001	0.001	0.000
0.250	0.00	3.	777.	1563.	1378.	1042.	2131.	0.317	0.001	0.001	0.000
0.300	0.00	4.	1010.	1993.	1758.	1328.	2139.	0.373	0.002	0.002	0.000
0.350	0.01	6.	1264.	2465.	2174.	1643.	2145.	0.427	0.002	0.002	0.000
0.400	0.01	8.	1539.	2980.	2629.	1986.	2151.	0.478	0.003	0.003	0.000
0.450	0.02	11.	1833.	3537.	3120.	2357.	2155.	0.527	0.004	0.003	0.000
0.500	0.02	14.	2146.	4137.	3649.	2757.	2159.	0.574	0.004	0.004	0.000
0.550	0.03	18.	2478.	4779.	4215.	3185.	2162.	0.618	0.005	0.005	0.000
0.600	0.05	22.	2834.	5475.	4829.	3649.	2165.	0.659	0.006	0.006	0.000
0.650	0.06	27.	3215.	6230.	5495.	4152.	2167.	0.699	0.007	0.007	0.000
0.700	0.08	32.	3623.	7045.	6215.	4696.	2169.	0.735	0.008	0.008	0.000
0.750	0.10	39.	4056.	7926.	6989.	5281.	2171.	0.770	0.009	0.009	0.001
0.800	0.12	45.	4515.	8866.	7821.	5909.	2172.	0.802	0.011	0.010	0.001
0.850	0.15	53.	4999.	9874.	8710.	6581.	2173.	0.831	0.012	0.011	0.001
0.900	0.19	62.	5508.	10948.	9657.	7296.	2173.	0.859	0.014	0.013	0.001
0.950	0.23	71.	6042.	12092.	10666.	8059.	2173.	0.883	0.015	0.014	0.001
1.000	0.27	81.	6610.	13322.	11752.	8879.	2173.	0.906	0.017	0.016	0.001
1.050	0.33	92.	7211.	14643.	12916.	9759.	2172.	0.926	0.019	0.017	0.001
1.100	0.38	104.	7847.	16057.	14164.	10701.	2171.	0.943	0.021	0.019	0.001
1.150	0.45	117.	8517.	17566.	15495.	11707.	2169.	0.959	0.023	0.021	0.002
1.200	0.53	132.	9220.	19172.	16912.	12777.	2167.	0.972	0.026	0.023	0.002
1.250	0.61	147.	9954.	20876.	18414.	13912.	2164.	0.982	0.029	0.026	0.002
1.300	0.70	164.	10718.	22675.	20002.	15112.	2161.	0.990	0.031	0.028	0.002
1.350	0.81	182.	11527.	24570.	21673.	16375.	2157.	0.996	0.035	0.030	0.003
1.400	0.92	201.	12730.	26556.	23425.	17698.	2153.	0.999	0.038	0.033	0.003
1.444	1.03	220.	13848.	28392.	25045.	18922.	2148.	1.000	0.041	0.035	0.003
PROPELLANT 1 BURNED OUT											
1.450	1.05	223.	13991.	28626.	25251.	19078.	2148.	1.000	0.042	0.036	0.003
1.500	1.19	246.	15307.	30774.	27146.	20509.	2142.	1.000	0.046	0.039	0.004
1.550	1.34	272.	16674.	32991.	29101.	21986.	2136.	1.000	0.050	0.042	0.004
1.600	1.51	300.	18086.	35261.	31103.	23499.	2129.	1.000	0.054	0.045	0.004
1.650	1.70	330.	19534.	37569.	33139.	25037.	2121.	1.000	0.059	0.048	0.005
1.700	1.91	363.	21010.	39895.	35191.	26588.	2113.	1.000	0.065	0.052	0.005
1.750	2.14	398.	22502.	42220.	37241.	28137.	2104.	1.000	0.070	0.055	0.006
1.800	2.39	435.	24000.	44518.	39269.	29668.	2094.	1.000	0.076	0.059	0.006
1.850	2.66	475.	25491.	46766.	41252.	31167.	2083.	1.000	0.082	0.063	0.007
1.900	2.96	517.	26963.	48939.	43168.	32614.	2072.	1.000	0.089	0.067	0.007
1.950	3.28	562.	28145.	51012.	44997.	33996.	2060.	1.000	0.095	0.071	0.008
2.000	3.63	608.	29224.	52963.	46718.	35296.	2048.	1.000	0.103	0.075	0.008
2.050	4.01	656.	30224.	54772.	48314.	36502.	2035.	1.000	0.110	0.079	0.009
2.100	4.42	705.	31137.	56423.	49771.	37602.	2021.	1.000	0.118	0.084	0.010
2.150	4.86	756.	31953.	57901.	51074.	38587.	2008.	1.000	0.126	0.088	0.010
2.200	5.33	808.	32668.	59196.	52216.	39450.	1994.	1.000	0.134	0.093	0.011
2.250	5.83	861.	33278.	60300.	53190.	40186.	1979.	1.000	0.143	0.097	0.011
2.300	6.36	915.	33780.	61210.	53993.	40792.	1965.	1.000	0.152	0.102	0.012
2.350	6.93	970.	34175.	61927.	54625.	41270.	1951.	1.000	0.161	0.107	0.013
2.400	7.53	1025.	34464.	62454.	55090.	41621.	1936.	1.000	[illegible]	0.112	0.014
2.450	8.16	1081.	34653.	62798.	55393.	41850.	1922.	1.000	[illegible]	[illegible].116	0.014
2.500	8.82	1137.	34745.	62968.	55544.	41964.	1908.	1.000	0.18[illegible]	[illegible].121	0.015

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4
2.527	9.20	1167.	34756.	62991.	55564.	41979.	1900.	1.000	0.194	0.124	0.015
LOCAL PRESSURE MAX DETECTED											
2.550	9.52	1193.	34746.	62975.	55550.	41969.	1894.	1.000	0.199	0.126	0.016
2.600	10.26	1249.	34665.	62832.	55424.	41873.	1880.	1.000	0.208	0.131	0.016
2.650	11.02	1304.	34507.	62552.	55176.	41686.	1866.	1.000	0.218	0.136	0.017
2.700	11.82	1360.	34281.	62148.	54821.	41418.	1853.	1.000	0.228	0.140	0.018
2.750	12.65	1415.	33995.	61636.	54368.	41076.	1840.	1.000	0.238	0.145	0.019
2.800	13.52	1469.	33656.	61028.	53832.	40671.	1827.	1.000	0.248	0.150	0.019
2.850	14.42	1523.	33271.	60338.	53223.	40211.	1815.	1.000	0.258	0.155	0.020
2.900	15.35	1576.	32848.	59578.	52553.	39704.	1803.	1.000	0.268	0.159	0.021
2.950	16.31	1629.	32392.	58760.	51832.	39160.	1791.	1.000	0.278	0.164	0.021
3.000	17.30	1680.	31910.	57895.	51069.	38583.	1780.	1.000	0.288	0.168	0.022
3.050	18.32	1731.	31408.	56993.	50273.	37982.	1768.	1.000	0.298	0.173	0.023
3.100	19.38	1782.	30890.	56062.	49452.	37361.	1758.	1.000	0.308	0.177	0.023
3.150	20.46	1831.	30360.	55110.	48612.	36727.	1747.	1.000	0.318	0.182	0.024
3.200	21.57	1879.	29823.	54145.	47761.	36084.	1737.	1.000	0.328	0.186	0.024
3.221	22.05	1900.	29586.	53719.	47385.	35800.	1733.	1.000	0.332	0.187	0.025
LAYER TRANSITION 2 TO 3 ON PERF SURFACE OF PROPELLANT 3											
LAYER TRANSITION 2 TO 3 ON END SURFACE OF PROPELLANT 3											
3.239	22.45	1916.	29419.	53420.	47121.	35601.	1730.	1.000	0.335	0.193	0.025
LAYER TRANSITION 3 TO 4 ON PERF SURFACE OF PROPELLANT 3											
LAYER TRANSITION 3 TO 4 ON END SURFACE OF PROPELLANT 3											
3.250	22.72	1927.	29348.	53292.	47009.	35516.	1727.	1.000	0.338	0.204	0.025
3.300	23.89	1974.	29024.	52712.	46497.	35129.	1717.	1.000	0.347	0.250	0.026
3.350	25.08	2020.	28684.	52105.	45961.	34724.	1707.	1.000	0.357	0.296	0.026
3.400	26.31	2066.	28332.	51474.	45405.	34304.	1698.	1.000	0.367	0.341	0.027
3.450	27.56	2112.	27970.	50826.	44833.	33872.	1689.	1.000	0.376	0.385	0.027
3.500	28.84	2156.	27601.	50163.	44249.	33431.	1680.	1.000	0.386	0.429	0.028
3.550	30.15	2200.	27225.	49490.	43654.	32982.	1672.	1.000	0.396	0.472	0.029
3.600	31.48	2244.	26844.	48809.	43054.	32528.	1664.	1.000	0.405	0.514	0.029
3.650	32.84	2287.	26461.	48123.	42448.	32071.	1656.	1.000	0.415	0.555	0.030
3.700	34.23	2329.	26077.	47434.	41841.	31612.	1648.	1.000	0.424	0.596	0.030
3.750	35.64	2371.	25693.	46746.	41234.	31153.	1641.	1.000	0.434	0.636	0.031
3.800	37.07	2412.	25310.	46059.	40628.	30695.	1634.	1.000	0.443	0.675	0.031
3.850	38.53	2452.	24928.	45375.	40025.	30240.	1627.	1.000	0.452	0.713	0.032
3.900	40.02	2492.	24549.	44697.	39426.	29787.	1621.	1.000	0.461	0.751	0.032
3.950	41.52	2531.	24174.	44024.	38833.	29339.	1615.	1.000	0.471	0.788	0.033
4.000	43.05	2570.	23802.	43359.	38246.	28896.	1609.	1.000	0.480	0.824	0.033
4.050	44.61	2608.	23435.	42701.	37666.	28458.	1603.	1.000	0.489	0.860	0.034
4.100	46.18	2646.	23073.	42053.	37094.	28025.	1597.	1.000	0.498	0.895	0.034
4.150	47.78	2682.	22716.	41413.	36530.	27599.	1591.	1.000	0.507	0.929	0.035
4.200	49.40	2719.	22364.	40784.	35975.	27180.	1586.	1.000	0.516	0.962	0.035
4.257	51.29	2760.	21973.	40084.	35357.	26713.	1580.	1.000	0.526	1.000	0.036
PROPELLANT 3 BURNED OUT											
4.300	52.71	2790.	21615.	39443.	34792.	26286.	1576.	1.000	0.533	1.000	0.036
4.350	54.39	2824.	21206.	38709.	34145.	25797.	1571.	1.000	0.542	1.000	0.036
4.400	56.10	2858.	20808.	37996.	33516.	25322.	1566.	1.000	0.550	1.000	0.037
4.450	57.82	2891.	20422.	37303.	32905.	24860.	1561.	1.000	0.559	1.000	0.037
4.500	59.57	2924.	20046.	36629.	32310.	24411.	1556.	1.000	0.567	1.000	0.038
4.550	61.33	2956.	19680.	35975.	31733.	23975.	1551.	1.000	0.575	1.000	0.038
4.600	63.11	2987.	19325.	35338.	31172.	23551.	1547.	1.000	0.583	1.000	0.039
4.650	64.91	3018.	18980.	34720.	30626.	23139.	1543.	1.000	0.592	1.000	0.039
4.700	66.73	3048.	18644.	34119.	30096.	22738.	1538.	1.000	0.600	1.000	0.039
4.750	68.57	3078.	18318.	33535.	29581.	22349.	1534.	1.000	0.607	1.000	0.040
4.800	70.43	3107.	18001.	32968.	29080.	21971.	1530.	1.000	0.615	1.000	0.040

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4
4.850	72.30	3136.	17693.	32416.	28594.	21603.	1526.	1.000	0.623	1.000	0.040
4.900	74.19	3164.	17393.	31879.	28120.	21246.	1522.	1.000	0.631	1.000	0.041
4.950	76.10	3192.	17101.	31358.	27660.	20898.	1519.	1.000	[illegible]	1.000	0.041
5.000	78.02	3219.	16818.	30851.	27213.	20560.	1515.	1.000	[illegible]	1.000	0.042
5.050	79.96	3246.	16542.	30357.	26778.	20231.	1511.	1.000	0.653	1.000	0.042
5.100	81.92	3272.	16274.	29878.	26355.	19912.	1508.	1.000	0.661	1.000	0.042
5.150	83.89	3298.	16012.	29411.	25943.	19601.	1504.	1.000	0.668	1.000	0.043
5.200	85.87	3324.	15758.	28957.	25543.	19298.	1501.	1.000	0.675	1.000	0.043
5.250	87.88	3349.	15511.	28515.	25153.	19003.	1497.	1.000	0.682	1.000	0.043
5.300	89.89	3374.	15270.	28085.	24773.	18717.	1494.	1.000	0.689	1.000	0.043
5.350	91.92	3398.	15036.	27666.	24404.	18437.	1491.	1.000	0.696	1.000	0.044
5.400	93.97	3422.	14807.	27258.	24044.	18166.	1488.	1.000	0.703	1.000	0.044
5.450	96.03	3446.	14585.	26861.	23694.	17901.	1485.	1.000	0.710	1.000	0.044
5.500	98.11	3469.	14368.	26474.	23352.	17643.	1482.	1.000	0.717	1.000	0.045
5.550	100.19	3492.	14157.	26097.	23020.	17392.	1479.	1.000	0.724	1.000	0.045
5.600	102.30	3515.	13951.	25729.	22695.	17147.	1476.	1.000	0.731	1.000	0.045
5.650	104.41	3537.	13750.	25371.	22379.	16908.	1473.	1.000	0.737	1.000	0.046
5.700	106.34	3559.	13554.	25022.	22071.	16675.	1470.	1.000	0.744	1.000	0.046
5.741	108.28	3577.	13399.	24745.	21827.	16491.	1468.	1.000	0.749	1.000	0.046

LAYER TRANSITION 2 TO 3 ON PERF SURFACE OF PROPELLANT 2
LAYER TRANSITION 2 TO 3 ON END SURFACE OF PROPELLANT 2
LAYER TRANSITION 2 TO 3 ON LAT SURFACE OF PROPELLANT 2

5.750	108.68	3581.	13364.	24683.	21773.	16450.	1468.	1.000	0.750	1.000	0.046
5.800	110.84	3602.	13198.	24387.	21512.	16252.	1467.	1.000	0.757	1.000	0.046
5.850	113.00	3623.	13069.	24159.	21310.	16100.	1469.	1.000	0.765	1.000	0.047
5.900	115.18	3644.	12983.	24009.	21178.	16000.	1474.	1.000	0.773	1.000	0.047
5.954	117.57	3667.	12949.	23951.	21127.	15962.	1486.	1.000	0.783	1.000	0.047

LAYER TRANSITION 3 TO 4 ON PERF SURFACE OF PROPELLANT 2
LAYER TRANSITION 3 TO 4 ON END SURFACE OF PROPELLANT 2
LAYER TRANSITION 3 TO 4 ON LAT SURFACE OF PROPELLANT 2

6.000	119.58	3686.	12949.	23954.	21130.	15964.	1498.	1.000	0.792	1.000	[illegible]

LOCAL PRESSURE MIN DETECTED

6.050	121.80	3707.	12947.	23956.	21131.	15965.	1511.	1.000	0.802	1.000	0.048
6.061	122.29	3711.	12947.	23956.	21131.	15966.	1514.	1.000	0.804	1.000	0.048

LOCAL PRESSURE MAX DETECTED

6.100	124.03	3728.	12945.	23955.	21131.	15965.	1524.	1.000	0.812	1.000	0.048
6.150	126.27	3749.	12931.	23935.	21113.	15952.	1536.	1.000	0.821	1.000	0.048
6.200	128.53	3769.	12878.	23843.	21032.	15891.	1545.	1.000	0.830	1.000	0.049
6.250	130.80	3790.	12804.	23714.	20918.	15805.	1553.	1.000	0.838	1.000	0.049
6.300	133.08	3811.	12715.	23559.	20781.	15701.	1559.	1.000	0.845	1.000	0.049
6.350	135.37	3831.	12616.	23383.	20626.	15584.	1564.	1.000	0.852	1.000	0.049
6.400	137.67	3851.	12507.	23192.	20457.	15457.	1569.	1.000	0.858	1.000	0.050
6.450	139.99	3871.	12391.	22987.	20276.	15320.	1573.	1.000	0.864	1.000	0.050
6.500	142.32	3891.	12269.	22771.	20086.	15176.	1576.	1.000	0.870	1.000	0.050
6.550	144.66	3911.	12142.	22546.	19887.	15026.	1579.	1.000	0.875	1.000	0.050
6.600	147.01	3930.	12011.	22313.	19682.	14871.	1581.	1.000	0.881	1.000	0.051
6.650	149.38	3949.	11877.	22074.	19471.	14712.	1583.	1.000	0.886	1.000	0.051
6.700	151.75	3968.	11739.	21831.	19256.	14550.	1584.	1.000	0.890	1.000	0.051
6.750	154.14	3987.	11600.	21583.	19038.	14385.	1585.	1.000	0.895	1.000	0.051
6.800	156.54	4006.	11459.	21332.	18817.	14218.	1585.	1.000	0.899	1.000	0.052
6.850	158.95	4024.	11316.	21079.	18593.	14049.	1585.	1.000	0.903	1.000	0.052
6.900	161.37	4042.	11173.	20824.	18368.	13879.	1585.	1.000	0.907	1.000	0.052
6.950	163.80	4060.	11028.	20567.	18142.	13708.	1585.	1.000	0.911	1.000	0.052
7.000	166.24	4078.	10884.	20310.	17915.	13537.	1584.	1.000	0.914	1.000	0.053
7.050	168.69	4095.	10739.	20053.	17689.	13366.	1583.	1.000	0.918	1.000	0.053

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4
7.100	171.15	4112.	10595.	19797.	17462.	13195.	1582.	1.000	0.921	1.000	0.053
7.150	173.63	4129.	10451.	19541.	17236.	13024.	1580.	1.000	0.924	1.000	0.053
7.200	176.11	4146.	10307.	19285.	17011.	12854.	1579.	1.000	0.927	1.000	0.054
7.250	178.60	4162.	10165.	19031.	16787.	12685.	1577.	1.000	0.930	1.000	0.054
7.300	181.10	4179.	10023.	18779.	16564.	12516.	1575.	1.000	0.932	1.000	0.054
7.350	183.62	4195.	9882.	18528.	16343.	12349.	1573.	1.000	0.935	1.000	0.054
7.400	186.14	4211.	9742.	18279.	16124.	12183.	1570.	1.000	0.937	1.000	0.054
7.419	187.11	4217.	9689.	18185.	16040.	12120.	1569.	1.000	0.938	1.000	0.054

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	2.527	7.419
TRAVEL (IN):	9.20	187.11
VELOCITY (FT/S)	1167.	4217.
ACCELERATION (G):	34756.	9689.
BREECH PRESS (PSI):	62991.	18135.
MEAN PRESS (PSI):	55564.	16040.
BASE PRESS (PSI):	41979.	12120.
MEAN TEMP (K):	1900.	1569.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.194	0.938
Z CHARGE 3 (-):	0.124	1.000
Z CHARGE 4 (-):	0.015	0.054

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	293665792.	100.00
(1) INTERNAL GAS:	191603776.	65.25
(2) WORK AND LOSSES:	102062016.	34.75
(A) PROJECTILE KINETIC:	69901328.	23.80
(B) GAS KINETIC:	22608000.	7.70
(C) PROJECTILE ROTATIONAL:	35195.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	391065.	0.13
(F) WORK DONE AGAINST AIR:	725224.	0.25
(G) HEAT CONVECTED TO BORE:	8401203.	2.86
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	1.175
CHARGE WT/PROJECTILE WT:	1.056
PIEZOMETRIC EFFICIENCY:	0.338
EXPANSION RATIO:	7.247

Test Case 6

Test case 6 is a two-part run with a $PMAX calculation in the first portion. The inputs are saved and re-used for a $PARA study on charge weight (second propellant deck) as a further set of calculations.

The $PMAX deck attempts to vary the web distance of the second propellant to reach a maximum breech pressure of 75 kpsi. Initial tries for the iterative solution are WEB=0.070 and WEB=0.075; these values establish a direction of search (WEB to increase or decrease). During execution, no output (other than input deck echoes) is printed until a solution has been found.

Ignition variations are in effect on propellant 2. The perforation surfaces are considered ignited at the start of calculation, end surfaces ignite at 0.2 milliseconds, and lateral surface when mean pressure reaches 2000 psi.

After the first solution has been found, IBHVG2 saves inputs to use for the second series of runs; namely, a $PARA study on charge weight for the second propellant. Values to be printed in the table at the end of the trajectory output have been specified in the first deck, and the $PMAX is still in effect to search for 75 kpsi maximum breech pressure by varying web distance.

```
$COMM
      IBHVG2 BENCHMARK TEST CASE 6

      SHOW IGNITION CODE VARIATIONS - PMAX .VS. PARA,PMAX

$HEAT
      TSHL = 0.00450          CSHL = 1848        RSHL = 0.284
      TWAL = 293              HO   = 0.0648      HL   = 1
$GUN
      NAME = '120MM GUN TEST CASE'    CHAM = 607        GRVE = 4.724
      LAND = 4.724            G/L  = 1.        TRAV = 187.11
      TWST = 99
$PROJ
      NAME = 'APFSDS'    PRWT = 15.65
$COMM
   'PDIS' VALUES USED WITH PARAMETRIC PRINT OPTION POPT(5)=2
$PDIS
 SHOW='PMAX' DECK='OUT'
$PDIS
 SHOW='CHWT' DECK='PROP' NTH=2
$PDIS
 SHOW='DIAM' DECK='PROP' NTH=2
$PDIS
 SHOW='PD' DECK='PROP' NTH=2
$PDIS
 SHOW='WEB' DECK='PROP' NTH=2
$PDIS
 SHOW='VMUZ' DECK='OUT'
$PDIS
 SHOW='ZMUZ(2)' DECK='OUT'
$PDIS
 SHOW='LDEN' DECK='OUT'

$RESI
      NPTS = 4               AIR  = 1
      TRAV =       0,    0.8,    5.0,   187
      PRES =     100,   2500,    100,   100

$INFO
      RUN  = '120MM IGNITION DELAY EXPERIMENT'   DELT = 5E-5  DELP = 5E-5
      GRAD = 2               POPT = 1,1,1,0,2    SOPT = 0
```

```
     EPS  = 0.05

$RECO
     NAME = 'NONE'          RECO = 0          RCWT = 0

$PRIM
     NAME = 'BENITE'        CHWT = 0.00347
                      GAMA = 1.25          FORC = 212500
     COV  = 30              TEMP = 2000
$PROP
     NAME = 'JA2 7P'        CHWT = 10.00       GRAN = '7PF'
     RHO  = 0.05732         GAMA = 1.2257      FORC = 382152
     COV  = 27.48            TEMP = 3400        EROS = 0.0000000
  NTBL=4 PR4L= 2000,4000,10000,25000 BR4L= 1.05,1.52,2.93,6.56
     LEN  = 0.643           DIAM = 0.420       PD   = 0.020
     WI   = 0.076           WO   = 0.074

$COMM
    PROPELLANT IGNITION CODES:
       PERF    IGNITES AT START OF CALCULATION
       END     IGNITES AT TIME=.2 MILLISECONDS
       LATERAL IGNITES WHEN MEAN PRESSURE REACHES 2KPSI

$PROP
     NAME = 'JA2 7P'        CHWT = 7.5       GRAN = '7PF'
     RHO  = 0.05732         GAMA = 1.2257      FORC = 382152
     COV  = 27.48            TEMP = 3400        EROS = 0.0000000
  NTBL=4 PR4L= 2000,4000,10000,25000 BR4L= 1.05,1.52,2.93,6.56
     LEN  = 0.643           DIAM = 0.420       PD   = 0.020
     WEB  = 0.075
    IGNS=0,1,3  THRS=0.,.0002,2000.

$COMM
    PROGRAM ITERATES WEB OF SECOND PROPELLANT UNTIL PMAX=75000 REACHED
              INITIAL GUESSES OF WEB ARE .070 AND .075 INCHES
$PMAX
    VARY='WEB' NTH=2 PMAX=75000 TRY1=0.070 TRY2=0.075
$END

$SAVE

$COMM
    VARY CHARGE WEIGHT OF SECOND PROPELLANT FROM 6 TO 8 POUNDS
      BY INCREMENTS OF .5 POUNDS
    ALL OTHER OPTIONS STILL IN FORCE AS IN PREVIOUS DECK
$PARA
 VARY='CW' NTH=2 FROM=6 TO=8 BY=0.5 DECK='PROP'
$END
```

Producing the following output:

```
ERRTOL=   4.768372E-07

CARD   1 --> $COMM
CARD   2 -->        IBHVG2 BENCHMARK TEST CASE 6
CARD   3 -->
CARD   4 -->        SHOW IGNITION CODE VARIATIONS - PMAX .VS. PARA,PMAX
CARD   5 -->
CARD   6 --> $HEAT
CARD   7 -->        TSHL = 0.00450        CSHL = 1848       RSHL = 0.284
CARD   8 -->        THAL = 293            HO   = 0.0648     HL   = 1
CARD   9 --> $GUN
CARD  10 -->        NAME = '120MM GUN TEST CASE'    CHAM = 607       GRVE = 4.724
CARD  11 -->        LAND = 4.724         G/L  = 1.        TRAV = 187.11
CARD  12 -->        TWST = 99
CARD  13 --> $PROJ
CARD  14 -->        NAME = 'APFSDS'   PRWT = 15.65
CARD  15 --> $COMM
CARD  16 -->    'PDIS' VALUES USED WITH PARAMETRIC PRINT OPTION POPT(5)=2
CARD  17 --> $PDIS
CARD  18 -->   SHOW='PMAX' DECK='OUT'
CARD  19 --> $PDIS
CARD  20 -->   SHOW='CHWT' DECK='PROP' NTH=2
CARD  21 --> $PDIS
CARD  22 -->   SHOW='DIAM' DECK='PROP' NTH=2
CARD  23 --> $PDIS
CARD  24 -->   SHOW='PD' DECK='PROP' NTH=2
CARD  25 --> $PDIS
CARD  26 -->   SHOW='WEB' DECK='PROP' NTH=2
CARD  27 --> $PDIS
CARD  28 -->   SHOW='VMUZ' DECK='OUT'
CARD  29 --> $PDIS
CARD  30 -->   SHOW='ZMUZ(2)' DECK='OUT'
CARD  31 --> $PDIS
CARD  32 -->   SHOW='LDEN' DECK='OUT'
CARD  33 -->
CARD  34 --> $RESI
CARD  35 -->        NPTS = 4              AIR  = 1
CARD  36 -->        TRAV =       0,    0.8,   3.0,   187
CARD  37 -->        PRES =     100,   2500,   100,   100
CARD  38 -->
CARD  39 --> $INFO
CARD  40 -->        RUN  = '120MM IGNITION DELAY EXPERIMENT'   DELT = 5E-5  DELP = 5E-5
CARD  41 -->        GRAD = 2              POPT = 1,1,1,0,2    SOPT = 0
CARD  42 -->        EPS  = 0.05
CARD  43 -->
CARD  44 --> $RECO
CARD  45 -->        NAME = 'NONE'         RECO = 0          RCWT = 0
CARD  46 -->
CARD  47 --> $PRIN
CARD  48 -->        NAME = 'BENITE'       CHWT = 0.00347
CARD  49 -->                      GAMA = 1.25        FORC = 212500
CARD  50 -->        COV  = 30             TEMP = 2000
CARD  51 --> $PROP
CARD  52 -->        NAME = 'JA2 7P'       CHWT = 10.00       GRAN = '7PF'
CARD  53 -->        RHO  = 0.05732        GAMA = 1.2257      FORC = 382152
CARD  54 -->        COV  = 27.48          TEMP = 3400        EROS = 0.0000000
CARD  55 -->    NTBL=4 PR4L= 2000,4000,10000,25000 BR4L= 1.05,1.52,2.93,6.56
```

```
CARD  56 -->        LEN  = 0.643        DIAM = 0.420      PD   = 0.020
CARD  57 -->        WI   = 0.076          WO   = 0.074
CARD  58 -->
CARD  59 --> $COMM
CARD  60 -->     PROPELLANT IGNITION CODES:
CARD  61 -->         PERF    IGNITES AT START OF CALCULATION
CARD  62 -->         END     IGNITES AT TIME=.2 MILLISECONDS
CARD  63 -->         LATERAL IGNITES WHEN MEAN PRESSURE REACHES 2KPSI
CARD  64 -->
CARD  65 --> $PROP
CARD  66 -->        NAME = 'JA2 7P'     CHWT = 7.5      GRAN = '7PF'
CARD  67 -->        RHO  = 0.05732      GAMA = 1.2257     FORC = 382152
CARD  68 -->        COV  = 27.48          TEMP = 3400       EROS = 0.0000000
CARD  69 -->    NTBL=4 PR4L= 2000,4000,10000,25000 BR4L= 1.05,1.52,2.93,6.56
CARD  70 -->        LEN  = 0.643        DIAM = 0.420      PD   = 0.020
CARD  71 -->        WEB = 0.075
CARD  72 -->       IGNS=0,1,3  THRS=0.,.0002,2000.
CARD  73 -->
CARD  74 --> $COMM
CARD  75 -->     PROGRAM ITERATES WEB OF SECOND PROPELLANT UNTIL PMAX=75000 REACHED
CARD  76 -->                INITIAL GUESSES OF WEB ARE .070 AND .075 INCHES
CARD  77 --> $PMAX
CARD  78 -->      VARY='WEB' NTH=2 PMAX=75000 TRY1=0.070 TRY2=0.075
CARD  79 --> $END
```

```
------------
- GUN TUBE -
------------

TYPE: 120MM GUN TEST CASE                  CHAMBER VOLUME (IN3):          607.00    TRAVEL (IN):                      187.11
GR[illegible] DIAMETER (IN):        4.724  LAND DIAMETER (IN):              4.724   GROOVE/LAND RATIO (-):             1.000
TW[illegible] (CAL/TURN):            99.0  BORE AREA (IN2):                17.5271  HEAT-LOSS OPTION:                      1
SHELL [illegible]SS (IN):        0.004500  SHELL CP (IN-LB/LB-K):           1848.0  SHELL DENSITY (LB/IN3):           0.2840
INIT[illegible] SHELL TEMP (K):      293.  AIR HO (IN-LB/IN2-S-K):         0.06480

--------------
- PROJECTILE -
--------------

TYPE: APFSDS                               TOTAL WEIGHT (LB):              15.650   WEIGHT PREDICTOR OPTION:               0

--------------
- RESISTANCE -
--------------

AIR RESISTANCE OPTION:          1          WALL HEATING FRACTION:          0.000    FRICTION TABLE LENGTH:                 4

 I   TRAVEL (IN)    PRESSURE (PSI)          I   TRAVEL (IN)    PRESSURE (PSI)        I   TRAVEL (IN)    PRESSURE (PSI)

 1      0.00           100.                 3      3.00           100.               4     187.00          100.
 2      0.80          2500.

-----------
- GENERAL -
-----------

MAX TIME STEP (S):          0.000050       PRINT STEP (S):              0.000050    MAX RELATIVE ERROR (-):          0.05000
PRINT OPTIONS:             1 1 1 0 2 1     STORE OPTION:                       0    CONSTANT-PRESSURE OPTION:              0
GRADIENT MODEL: PIDDUCK-KENT

----------
- RECOIL -
----------

RECOIL OPTION:                  0          TYPE: NONE                               RECOILING WEIGHT (LB):                0.

----------
-  IMER -
----------

TYPE: BENITE                               GAMMA (-):                      1.2500   FORCE (FT-LB/LB):                212500.
COVOLUME (IN3/LB):         30.000          FLAME TEMP (K):                 2000.0   WEIGHT (LB):                    0.003470
```

- CHARGE 1 -

TYPE: JA2 7P		GRAINS:	2724.4 7PF	WEIGHT (LB):	10.0000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.64300	GRAIN DIAMETER (IN):	0.36000	PERF DIAMETER (IN):	0.02000
INNER WEB (IN):	0.07600	OUTER WEB (IN):	0.07400		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES			
		2ND	3RD	4TH
AT DEPTH (IN):		------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.
COVOLUME (IN3/LB):	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES			
	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.
COVOLUME (IN3/LB):	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			
	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.
COVOLUME (IN3/LB):	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56

- CHARGE 2 -

TYPE: JA2 7		GRAINS:	3283.5 7PF	WEIGHT (LB):	7.5000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
P-SURFACE IGN CODE:	0	E-SURFACE IGN CODE:	1	L-SURFACE IGN CODE:	3
P-SURF IGN AT (S):	0.00000E+00	E-SURF IGN AT (S):	0.20000E-03	L-SURF IGN AT (PSI):	0.20000E+04
GRAIN LENGTH (IN):	0.64300	GRAIN DIAMETER (IN):	0.28585	PERF DIAMETER (IN):	0.02000
INNER WEB (IN):	0.05646	OUTER WEB (IN):	0.05646		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES 1ST	2ND	3RD	4TH	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.	------	------	------	382152.
COVOLUME (IN3/LB).	------	------	------	27.480	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56	------	------	------	6.56

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES 1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.
COVOLUME (IN3/LB):	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
0.000	0.00	0.	0.	29.	29.	29.	2000.	0.000	0.000
0.050	0.00	0.	0.	54.	54.	54.	2490.	0.000	0.000
0.100	0.00	0.	0.	87.	87.	87.	2779.	0.000	0.000
0.120	0.00	0.	0.	102.	102.	102.	2859.	0.000	0.000
SHOT-START PRESSURE ACHIEVED									
0.150	0.00	0.	-6.	145.	127.	95.	2954.	0.000	0.000
0.202	0.00	0.	37.	203.	178.	133.	3072.	0.001	0.000
PROPELLANT 2 IGNITED ON END SURFACE									
0.250	0.00	0.	88.	273.	240.	179.	3151.	0.001	0.000
0.300	0.00	0.	149.	357.	313.	234.	3207.	0.001	0.001
0.350	0.00	1.	219.	454.	398.	297.	3247.	0.002	0.001
0.400	0.00	1.	297.	562.	493.	368.	3275.	0.002	0.001
0.450	0.00	2.	384.	684.	600.	448.	3297.	0.003	0.001
0.500	0.00	2.	478.	818.	718.	535.	3313.	0.003	0.002
0.550	0.00	3.	581.	966.	847.	632.	3326.	0.004	0.002
0.600	0.01	4.	691.	1126.	988.	737.	3337.	0.005	0.002
0.650	0.01	5.	809.	1300.	1141.	851.	3345.	0.005	0.003
0.700	0.01	7.	935.	1488.	1305.	974.	3351.	0.006	0.003
0.750	0.02	8.	1067.	1690.	1482.	1106.	3357.	0.007	0.004
0.800	0.02	10.	1207.	1905.	1671.	1247.	3362.	0.008	0.004
0.850	0.03	12.	1352.	2135.	1873.	1397.	3365.	0.009	0.005
0.880	0.03	14.	1442.	2278.	1998.	1491.	3367.	0.009	0.005
PROPELLANT 2 IGNITED ON LAT SURFACE									
0.900	0.04	15.	1534.	2420.	2123.	1584.	3369.	0.010	0.005
0.950	0.05	17.	1773.	2790.	2447.	1826.	3373.	0.011	0.007
1.000	0.06	20.	2028.	3188.	2797.	2087.	3375.	0.012	0.008
1.050	0.07	24.	2297.	3615.	3172.	2366.	3378.	0.013	0.010
1.100	0.09	28.	2579.	4071.	3572.	2665.	3379.	0.014	0.012
1.150	0.11	32.	2874.	4556.	3997.	2982.	3381.	0.016	0.014
1.200	0.13	37.	3185.	5075.	4452.	3322.	3382.	0.017	0.016
1.250	0.15	42.	3516.	5635.	4944.	3689.	3382.	0.019	0.018
1.300	0.18	48.	3866.	6238.	5472.	4083.	3382.	0.021	0.020
1.350	0.21	55.	4236.	6884.	6039.	4506.	3383.	0.023	0.023
1.400	0.24	62.	4626.	7576.	6646.	4959.	3382.	0.025	0.025
1.450	0.28	70.	5035.	8316.	7295.	5443.	3382.	0.027	0.028
1.500	0.33	78.	5463.	9103.	7986.	5958.	3381.	0.029	0.031
1.550	0.38	87.	5910.	9941.	8720.	6507.	3380.	0.032	0.034
1.600	0.43	97.	6375.	10829.	9499.	7088.	3379.	0.034	0.038
1.650	0.49	108.	6858.	11769.	10324.	7703.	3378.	0.037	0.042
1.700	0.56	119.	7366.	12775.	11206.	8361.	3376.	0.040	0.046
1.750	0.64	132.	7901.	13850.	12149.	9065.	3374.	0.043	0.050
1.800	0.72	145.	8464.	14998.	13157.	9817.	3372.	0.047	0.055
1.850	0.81	159.	9101.	16223.	14231.	10618.	3370.	0.051	0.060
1.900	0.91	174.	10178.	17526.	15375.	11472.	3367.	0.055	0.065
1.950	1.02	192.	11326.	18911.	16589.	12378.	3364.	0.059	0.071
2.000	1.14	211.	12549.	20378.	17876.	13338.	3361.	0.064	0.077
2.050	1.27	232.	13848.	21929.	19237.	14353.	3358.	0.069	0.084
2.100	1.42	255.	15224.	23565.	20671.	15424.	3354.	0.074	0.091
2.150	1.58	281.	16680.	25283.	22179.	16549.	3349.	0.080	0.098
2.200	1.76	309.	18215.	27084.	23758.	17727.	3344.	0.086	0.107
2.250	1.95	340.	19830.	28963.	25407.	18957.	3339.	0.092	0.115
2.300	2.17	373.	21523.	30919.	27123.	20237.	3333	0.099	0.125
2.350	2.40	409.	23294.	32944.	28900.	21563.	3326.	0.107	0.134
2.400	2.66	448.	25138.	35033.	30732.	22930.	3319.	0.115	0.145
2.450	2.94	490.	27053.	37178.	32614.	24334.	3312.	0.123	0.156

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
2.500	3.25	535.	28732.	39369.	34535.	25768.	3304.	0.132	0.168
2.550	3.58	583.	30363.	41595.	36488.	27225.	3295.	0.141	0.180
2.600	3.95	633.	32011.	43846.	38463.	28699.	3285.	0.151	0.193
2.650	4.34	686.	33668.	46110.	40449.	30180.	3276.	0.161	0.207
2.700	4.77	741.	35324.	48372.	42433.	31661.	3265.	0.172	0.222
2.750	5.23	800.	36969.	50619.	44404.	33132.	3254.	0.183	0.237
2.800	5.73	860.	38592.	52837.	46350.	34583.	3243.	0.195	0.253
2.850	6.26	924.	40182.	55010.	48256.	36006.	3231.	0.207	0.270
2.900	6.84	990.	41729.	57125.	50111.	37390.	3218.	0.220	0.288
2.950	7.45	1058.	43222.	59166.	51902.	38726.	3205.	0.233	0.306
3.000	8.11	1129.	44651.	61121.	53617.	40005.	3192.	0.247	0.325
3.050	8.81	1202.	46007.	62976.	55244.	41220.	3178.	0.262	0.344
3.100	9.55	1277.	47281.	64720.	56774.	42361.	3165.	0.277	0.365
3.150	10.34	1354.	48466.	66343.	58198.	43423.	3150.	0.292	0.386
3.200	11.18	1433.	49556.	67836.	59508.	44401.	3136.	0.308	0.407
3.250	12.06	1514.	50545.	69193.	60698.	45289.	3121.	0.324	0.429
3.300	12.99	1596.	51430.	70409.	61764.	46084.	3107.	0.340	0.452
3.350	13.97	1679.	52209.	71479.	62703.	46785.	3092.	0.357	0.476
3.400	15.01	1764.	52880.	72404.	63514.	47390.	3077.	0.374	0.499
3.450	16.09	1849.	53444.	73182.	64197.	47900.	3062.	0.392	0.524
3.500	17.23	1936.	53901.	73816.	64753.	48315.	3048.	0.410	0.548
3.550	18.41	2023.	54255.	74309.	65186.	48638.	3033.	0.428	0.573
3.600	19.65	2110.	54509.	74666.	65499.	48871.	3018.	0.446	0.599
3.650	20.95	2198.	54666.	74891.	65697.	49019.	3004.	0.464	0.624
3.700	22.29	2286.	54731.	74992.	65785.	49085.	2989.	0.483	0.650
3.718	22.78	2318.	54734.	75000.	65792.	49090.	2984.	0.489	0.659
LOCAL PRESSURE MAX DETECTED									
3.718	22.78	2318.	54734.	75000.	65792.	49090.	2984.	0.489	0.659
LOCAL PRESSURE MIN DETECTED									
3.718	22.78	2318.	54734.	75000.	65792.	49090.	2984.	0.489	0.659
LOCAL PRESSURE MAX DETECTED									
3.750	23.69	2375.	54711.	74976.	65771.	49074.	2975.	0.501	0.676
3.800	25.14	2463.	54609.	74850.	65660.	48991.	2961.	0.520	0.703
3.850	26.65	2550.	54432.	74622.	65460.	48842.	2947.	0.539	0.729
3.900	28.20	2638.	54186.	74300.	65177.	48631.	2934.	0.558	0.756
3.950	29.81	2725.	5[illegible]77.	73892.	64820.	48364.	2920.	0.577	0.782
4.000	31.47	2811.	53[illegible]11.	73406.	64394.	48047.	2907.	0.596	0.809
4.050	33.18	2897.	53093.	72851.	63907.	47683.	2894.	0.615	0.836
4.100	34.95	2982.	52620.	72220.	63353.	47270.	2881.	0.634	0.862
4.150	36.76	3066.	51925.	71287.	62535.	46660.	2868.	0.652	0.884
4.200	38.63	3149.	51047.	70104.	61497.	45885.	2853.	0.671	0.902
4.250	40.54	3231.	50062.	68776.	60332.	45016.	2838.	0.690	0.917
4.300	42.50	3310.	4900[illegible].	67350.	59081.	44082.	2822.	0.708	0.930
[illegible].350	44.51	3388.	4790[illegible].	65858.	57772.	43106.	2807.	0.726	0.941
4.400	46.57	3465.	46765.	64324.	56426.	42102.	2791.	0.744	0.950
4.450	48.67	3539.	45611.	62766.	55060.	41082.	2776.	0.761	0.958
4.500	50.82	3611.	44451.	61199.	53685.	40056.	2760.	0.778	0.965
4.550	53.00	3682.	43295.	59636.	52314.	39033.	2745.	0.795	0.970
4.600	55.23	3751.	42155.	58097.	50964.	38026.	2730.	0.811	0.975
4.650	57.51	3818.	41038.	56587.	49639.	37038.	2715.	0.827	0.980
4.700	59.82	3883.	39944.	55109.	48343.	36071.	2701.	0.843	0.983
4.750	62.16	3947.	38876.	53667.	47078.	35127.	2686.	0.859	0.987
4.800	64.55	4008.	37808.	52224.	45812.	34182.	2672.	0.873	0.990
4.850	66.97	4068.	36739.	50780.	44545.	33237.	2657.	0.886	0.992
4.900	69.43	4127.	35653.	49313.	43258.	32276.	2642.	0.897	0.994

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
4.950	71.93	4183.	34568.	47846.	41972.	31317.	2627.	0.907	0.996
5.000	74.45	4238.	33499.	46401.	40705.	30371.	2611.	0.916	0.997
5.050	77.01	4291.	32452.	44987.	39464.	29445.	2596.	0.923	0.998
5.100	79.60	4342.	31432.	43608.	38254.	28543.	2581.	0.930	0.999
5.150	82.22	4392.	30440.	42268.	37079.	27666.	2565.	0.936	0.999
5.200	84.87	4440.	29479.	40969.	35939.	[illegible]	2550.	0.942	1.000
5.250	87.55	4487.	28549.	39713.	34837.	[illegible]	2535.	0.947	1.000
5.251	87.61	4488.	28528.	39684.	34812.	[illegible]	2535.	0.947	1.000
PROPELLANT 2 BURNED OUT									
5.300	90.25	4532.	27652.	38501.	33774.	25200.	2520.	0.952	1.000
5.350	92.99	4576.	26789.	37335.	32751.	24437.	2505.	0.956	1.000
5.400	95.75	4619.	25959.	36214.	31768.	23703.	2491.	0.960	1.000
5.450	98.53	4660.	25161.	35137.	30823.	22978.	2476.	0.963	1.000
5.500	101.34	4700.	24394.	34102.	29915.	22321.	2462.	0.966	1.000
5.550	104.17	4738.	23657.	33107.	29042.	21670.	2448.	0.969	1.000
5.600	107.02	4776.	22949.	32152.	28204.	21044.	2434.	0.972	1.000
5.650	109.90	4812.	22269.	31234.	27399.	20444.	2421.	0.974	1.000
5.700	112.80	4848.	21615.	30352.	26626.	19867.	2407.	0.976	1.000
5.750	115.72	4882.	20988.	29506.	25884.	19313.	2394.	0.978	1.000
5.800	118.65	4915.	20386.	28695.	25172.	18781.	2381.	0.980	1.000
5.850	121.61	4947.	19808.	27916.	24488.	18272.	2369.	0.982	1.000
5.900	124.59	4979.	19253.	27168.	23832.	17782.	2356.	0.983	1.000
5.950	127.59	5009.	18720.	26450.	23202.	17312.	2344.	0.985	1.000
6.000	130.60	5039.	18208.	25760.	22597.	16861.	2332.	0.986	1.000
6.050	133.64	5068.	17716.	25097.	22015.	16427.	2320.	0.987	1.000
6.100	136.68	5096.	17242.	24459.	21456.	16009.	2309.	0.988	1.000
6.150	139.75	5124.	16787.	23846.	20918.	15608.	2297.	0.989	1.000
6.200	142.83	5150.	16348.	23256.	20400.	15222.	2286.	0.990	1.000
6.250	145.93	5176.	15926.	22688.	19902.	14850.	2275.	0.991	1.000
6.300	149.04	5202.	15519.	22141.	19422.	14492.	2264.	0.992	1.000
6.350	152.17	5226.	15128.	21613.	18960.	14147.	2253.	0.993	1.000
6.400	155.32	5250.	[illegible]	21105.	18514.	13814.	2243.	0.994	1.000
6.450	158.47	5274.	14385.	20616.	18085.	13494.	2232.	0.994	1.000
6.500	161.64	5297.	14034.	20143.	17670.	13184.	2222.	0.995	1.000
6.550	164.83	5319.	13695.	19687.	17270.	12886.	2212.	0.996	1.000
6.600	168.03	5341.	13367.	19247.	16884.	12598.	2202.	0.996	1.000
6.650	171.24	5362.	13051.	18822.	16512.	12320.	2192.	0.997	1.000
6.700	174.46	5383.	12745.	18412.	16151.	12051.	2182.	0.997	1.000
6.750	177.70	5403.	12450.	18015.	15803.	11792.	2173.	0.997	1.000
6.800	180.94	5423.	12164.	17632.	15467.	11541.	2164.	0.998	1.000
6.850	184.20	5442.	11888.	17261.	15142.	11298.	2154.	0.998	1.000
6.894	187.11	5459.	11650.	16942.	14862.	11089.	2146.	0.998	1.000

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	3.718	6.894
TRAVEL (IN):	22.78	187.11
VELOCITY (FT/S)	2318.	5459.
ACCELERATION (G):	54734.	11650.
BREECH PRESS (PSI):	75000.	16942.
MEAN PRESS (PSI):	65792.	14862.
BASE PRESS (PSI):	49090.	11089.
MEAN TEMP (K):	2984.	2146.
Z CHARGE 1 (-):	0.489	0.998
Z CHARGE 2 (-):	0.659	1.000

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	355233280.	100.00
(1) INTERNAL GAS:	224251200.	63.13
(2) WORK AND LOSSES:	130982080.	36.87
(A) PROJECTILE KINETIC:	86906272.	24.46
(B) GAS KINETIC:	29568784.	8.32
(C) PROJECTILE ROTATIONAL:	43757.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	391060.	0.11
(F) WORK DONE AGAINST AIR:	1221806.	0.34
(G) HEAT CONVECTED TO BORE:	12850402.	3.62
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	0.798
CHARGE WT/PROJECTILE WT:	1.118
PIEZOMETRIC EFFICIENCY:	0.353
EXPANSION RATIO:	6.403

```
CARD  80 -->
CARD  81 --> $SAVE
CARD  82 -->
CARD  83 --> $COMM
CARD  84 -->     VARY CHARGE WEIGHT OF SECOND PROPELLANT FROM 6 TO 8 POUNDS
CARD  85 -->       BY INCREMENTS OF .5 POUNDS
CARD  86 -->     ALL OTHER OPTIONS STILL IN FORCE AS IN PREVIOUS DECK
CARD  87 --> $PARA
CARD  88 -->  VARY='CW' NTH=2 FROM=6 TO=8 BY=0.5 DECK='PROP'
CARD  89 --> $END
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- GUN TUBE -
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  TYPE: 120MM GUN TEST CASE               CHAMBER VOLUME (IN3):       607.00    TRAVEL (IN):                   187.11
  GROOVE DIAMETER (IN):          4.724    LAND DIAMETER (IN):          4.724    GROOVE/LAND RATIO (-):          1.000
  TWIST (CALS/TURN):              99.0    BORE AREA (IN2):           17.5271    HEAT-LOSS OPTION:                   1
  SHELL THICKNESS (IN):       0.004500    SHELL CP (IN-LB/LB-K):      1848.0    SHELL DENSITY (LB/IN3):        0.2840
  INITIAL SHELL TEMP (K):         293.    AIR HO (IN-LB/IN2-S-K):    0.06480

--------------
- PROJECTILE -
--------------

  TYPE: APFSDS                            TOTAL WEIGHT (LB):          15.650    WEIGHT PREDICTOR OPTION:            0

--------------
- RESISTANCE -
--------------

  AIR RESISTANCE OPTION:             1    WALL HEATING FRACTION:       0.000    FRICTION TABLE LENGTH:              4

   I   TRAVEL (IN)    PRESSURE (PSI)       I   TRAVEL (IN)    PRESSURE (PSI)     I   TRAVEL (IN)    PRESSURE (PSI)

   1       0.00            100.            3       3.00            100.          4    187.00             100.
   2       0.80           2500.

-----------
- GENERAL -
-----------

  MAX TIME STEP (S):          0.000050    PRINT STEP (S):           0.000050    MAX RELATIVE ERROR (-):   0.05000
  PRINT OPTIONS:           1 1 1 0 2 1    STORE OPTION:                    0    CONSTANT-PRESSURE OPTION:         0
  GRADIENT MODEL: PIDDUCK-KENT

----------
- RECOIL -
----------

  RECOIL OPTION:                     0    TYPE: NONE                            RECOILING WEIGHT (LB):             0.

----------
- PRIMER -
----------

  TYPE: BENITE                            GAMMA (-):                  1.2500    FORCE (FT-LB/LB):             212500.
  COVOLUME (IN3/LB):            30.000    FLAME TEMP (K):             2000.0    WEIGHT (LB):                 0.003470
```

- CHARGE 1 -

TYPE: JA2 7P		GRAINS:	2724.4 7PF	WEIGHT (LB):	10.0000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.64300	GRAIN DIAMETER (IN):	0.36000	PERF DIAMETER (IN):	0.02000
INNER WEB (IN):	0.07600	OUTER WEB (IN):	0.07400		

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES				PROPERTIES AT LAYER BOUNDARIES OF END SURFACES			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.	------	------	------	382152.
COVOLUME (IN3/LB):	------	------	------	27.480	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56	------	------	------	6.56

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			
	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.
COVOLUME (IN3/LB):	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56

- CHARGE 2 -

TYPE: JA2 7P		GRAINS:	4241.2 7PF	WEIGHT (LB):	6.0000
EROSIVE COEFF (-):	0.000000	CHARGE IGN CODE:	0	CHARGE IGN AT (S):	0.00000E+00
P-SURFACE IGN CODE:	0	E-SURFACE IGN CODE:	1	L-SURFACE IGN CODE:	3
P-SURF IGN AT (S):	0.00000E+00	E-SURF IGN AT (S):	0.20000E-03	L-SURF IGN AT (PSI):	0.20000E+04
GRAIN LENGTH (IN):	0.64300	GRAIN DIAMETER (IN):	0.22731	PERF DIAMETER (IN):	0.02000
INNER WEB (IN):	0.04183	OUTER WEB (IN):	0.04183		

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.
COVOLUME (IN3/LB):	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.
COVOLUME (IN3/LB):	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	------	------	------	0.00000
ADJACENT LAYER WT %:	------	------	------	100.000
DENSITY (LB/IN3):	------	------	------	0.05732
GAMMA (-):	------	------	------	1.2257
FORCE (FT-LB/LB):	------	------	------	382152.
COVOLUME (IN3/LB):	------	------	------	27.480
FLAME TEMP (K):	------	------	------	3400.0
MEAN PRESSURES (PSI):	------	------	------	2000.0
MEAN PRESSURES (PSI):	------	------	------	4000.0
MEAN PRESSURES (PSI):	------	------	------	10000.0
MEAN PRESSURES (PSI):	------	------	------	25000.0
BURNING RATES (IN/S):	------	------	------	1.05
BURNING RATES (IN/S):	------	------	------	1.52
BURNING RATES (IN/S):	------	------	------	2.93
BURNING RATES (IN/S):	------	------	------	6.56

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
0.000	0.00	0.	0.	27.	27.	27.	2000.	0.000	0.000
0.050	0.00	0.	0.	50.	50.	50.	2496.	0.000	0.000
0.100	0.00	0.	0.	81.	81.	81.	2786.	0.000	0.000
0.126	0.00	0.	0.	100.	100.	100.	2837.	0.000	0.000
SHOT-START PRESSURE ACHIEVED									
0.149	0.00	0.	-11.	134.	119.	90.	2960.	0.000	0.000
0.201	0.00	0.	30.	189.	167.	127.	3078.	0.001	0.000
PROPELLANT 2 IGNITED ON END SURFACE									
0.250	0.00	0.	79.	254.	224.	171.	3155.	0.001	0.001
0.300	0.00	0.	137.	331.	293.	223.	3210.	0.001	0.001
0.350	0.00	1.	203.	419.	371.	282.	3248.	0.002	0.001
0.400	0.00	1.	276.	518.	459.	349.	3277.	0.002	0.002
0.450	0.00	1.	358.	629.	557.	424.	3298.	0.003	0.002
0.500	0.00	2.	447.	752.	665.	507.	3314.	0.003	0.002
0.550	0.00	3.	543.	886.	784.	597.	3327.	0.004	0.003
0.600	0.01	4.	647.	1033.	914.	696.	3337.	0.004	0.003
0.650	0.01	5.	758.	1192.	1054.	803.	3345.	0.005	0.004
0.700	0.01	6.	875.	1363.	1205.	918.	3352.	0.006	0.004
0.750	0.02	8.	1000.	1546.	1368.	1042.	3357.	0.007	0.005
0.800	0.02	10.	1130.	1743.	1542.	1174.	3362.	0.007	0.006
0.850	0.03	11.	1267.	1952.	1727.	1315.	3365.	0.008	0.006
0.900	0.04	14.	1409.	2174.	1923.	1464.	3369.	0.009	0.007
0.919	0.04	14.	1463.	2259.	1999.	1522.	3370.	0.010	0.007
PROPELLANT 2 IGNITED ON LAT SURFACE									
0.950	0.04	16.	1603.	2470.	2185.	1664.	3372.	0.010	0.009
1.000	0.05	19.	1836.	2826.	2499.	1903.	3375.	0.011	0.010
1.050	0.07	22.	2083.	3207.	2837.	2160.	3377.	0.013	0.013
1.100	0.08	25.	2343.	3614.	3197.	2435.	3379.	0.014	0.015
1.150	0.10	29.	2614.	4048.	3581.	2727.	3381.	0.015	0.017
1.200	0.12	34.	2897.	4508.	3988.	3037.	3382.	0.016	0.020
1.250	0.14	39.	3195.	4999.	4422.	3368.	3383.	0.018	0.022
1.300	0.16	44.	3509.	5527.	4889.	3723.	3383.	0.020	0.025
1.350	0.19	50.	3842.	6094.	5390.	4105.	3383.	0.021	0.028
1.400	0.22	57.	4192.	6700.	5927.	4514.	3383.	0.023	0.032
1.450	0.26	64.	4559.	7349.	6500.	4950.	3383.	0.025	0.035
1.500	0.30	71.	4944.	8039.	7111.	5415.	3383.	0.027	0.039
1.550	0.34	80.	5346.	8773.	7761.	5910.	3382.	0.030	0.043
1.600	0.40	88.	5765.	9553.	8451.	6435.	3381.	0.032	0.047
1.650	0.45	98.	6200.	10379.	9181.	6992.	3380.	0.035	0.052
1.700	0.51	108.	6650.	11252.	9953.	7580.	3379.	0.037	0.057
1.750	0.58	120.	7120.	12179.	10773.	8204.	3377.	0.040	0.062
1.800	0.66	131.	7613.	13168.	11649.	8871.	3376.	0.044	0.068
1.850	0.74	144.	8132.	14224.	12583.	9582.	3374.	0.047	0.074
1.900	0.83	158.	8813.	15348.	13577.	10340.	3372.	0.051	0.081
1.950	0.93	173.	9836.	16544.	14635.	11145.	3369.	0.054	0.088
2.000	1.04	189.	10926.	17813.	15758.	12000.	3366.	0.059	0.095
2.050	1.16	208.	12085.	19158.	16947.	12906.	3364.	0.063	0.103
2.100	1.29	228.	13317.	20580.	18205.	13864.	3360.	0.068	0.112
2.150	1.43	251.	14622.	22078.	19531.	14873.	3357.	0.073	0.121
2.200	1.59	275.	16004.	23655.	20925.	15936.	3353.	0.078	0.131
2.250	1.76	302.	17463.	25309.	22388.	17050.	3348.	0.084	0.142
2.300	1.95	332.	18999.	27039.	23919.	18215.	3343.	0.090	0.153
2.350	2.16	364.	20613.	28842.	25514.	19430.	3338.	0.097	0.165
2.400	2.39	398.	22305.	30715.	27171.	20692.	3332.	0.104	0.178
2.450	2.64	435.	24072.	32654.	28886.	21998.	3326.	0.111	0.191

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
2.500	2.91	476.	25912.	34653.	30654.	23345.	3319.	0.119	0.206
2.550	3.21	519.	27567.	36705.	32469.	24727.	3311.	0.127	0.22[illegible]
2.600	3.53	564.	29147.	38802.	34324.	26139.	3303.	0.136	0.237
2.650	3.89	613.	30756.	40936.	36212.	27577.	3295.	0.145	0.254
2.700	4.27	663.	32384.	43097.	38124.	29033.	3286.	0.155	0.273
2.750	4.68	717.	34025.	45275.	40051.	30500.	3276.	0.165	0.292
2.800	5.13	773.	35671.	47459.	41982.	31971.	3266.	0.176	0.312
2.850	5.61	832.	37311.	49636.	43908.	33438.	3256.	0.187	0.333
2.900	6.13	893.	38936.	51795.	45818.	34892.	3245.	0.199	0.355
2.950	6.69	957.	40538.	53921.	47699.	36325.	3233.	0.211	0.378
3.000	7.28	1024.	42106.	56003.	49541.	37727.	3222.	0.224	0.403
3.050	7.91	1093.	43630.	58028.	51332.	39091.	3209.	0.237	0.428
3.100	8.59	1164.	45101.	59984.	53062.	40409.	3197.	0.251	0.454
3.150	9.31	1238.	46511.	61858.	54719.	41671.	3184.	0.265	0.482
3.200	10.08	1314.	47850.	63639.	56296.	42871.	3171.	0.280	0.510
3.250	10.89	1392.	49113.	65319.	57781.	44003.	3157.	0.295	0.540
3.300	11.75	1472.	50291.	66888.	59169.	45059.	3144.	0.311	0.570
3.350	12.66	1554.	51380.	68338.	60452.	46037.	3130.	0.327	0.602
3.400	13.61	1637.	52374.	69664.	61625.	46930.	3116.	0.343	0.634
3.450	14.62	1722.	53271.	70862.	62685.	47737.	3102.	0.360	0.667
3.500	15.68	1809.	54069.	71928.	63627.	48455.	3088.	0.377	0.701
3.550	16.79	1896.	54765.	72860.	64453.	49083.	3074.	0.395	0.735
3.600	17.96	1985.	55361.	73660.	65160.	49622.	3059.	0.413	0.771
3.650	19.17	2075.	55856.	74327.	65750.	50071.	3045.	0.431	0.807
3.700	20.45	2165.	56253.	74864.	66225.	50433.	3031.	0.449	0.844
3.729	21.21	2218.	56351.	75000.	66345.	50525.	3023.	0.460	0.863
LOCAL PRESSURE MAX DETECTED									
3.729	21.21	2218.	56351.	75000.	66345.	50525.	3023.	0.460	0.863
LOCAL PRESSURE MIN DETECTED									
3.729	21.21	2218.	56351.	75000.	66345.	50525.	3023.	0.460	0.863
LOCAL PRESSURE MAX DETECTED									
3.750	21.77	2256.	56305.	74944.	66296.	50487.	3016.	0.468	0.875
3.800	23.15	2346.	55943.	74476.	65882.	50172.	3000.	0.487	0.900
3.850	24.59	2436.	55323.	73668.	65167.	49627.	2982.	0.505	0.920
3.900	26.07	2524.	54512.	72605.	64227.	48911.	2964.	0.524	0.936
3.950	27.62	2611.	53552.	71345.	63112.	48062.	2946.	0.542	0.949
4.000	29.21	2696.	52476.	69932.	61862.	47110.	2927.	0.561	0.960
4.050	30.85	2780.	51317.	68409.	60515.	46084.	2909.	0.579	0.969
4.100	32.54	2862.	50116.	66830.	59118.	45021.	2890.	0.596	0.976
4.150	34.28	2941.	48889.	65218.	57692.	43935.	2872.	0.614	0.982
4.200	36.07	3019.	47649.	63586.	56249.	42836.	2854.	0.631	0.987
4.250	37.91	3095.	46404.	61950.	54801.	41733.	2836.	0.648	0.991
4.300	39.79	3168.	45163.	60318.	53358.	40634.	2819.	0.664	0.994
4.350	41.71	3240.	43933.	58701.	51927.	39545.	2801.	0.680	0.997
4.400	43.67	3310.	42719.	57105.	50516.	38470.	2784.	0.696	0.998
4.450	45.68	3378.	41526.	55537.	49128.	37413.	2768.	0.712	0.999
4.500	47.73	3444.	40357.	54000.	47769.	36378.	2751.	0.727	1.000
4.511	48.19	3458.	40096.	53658.	47466.	36147.	2748.	0.731	1.000
PROPELLANT 2 BURNED OUT									
4.549	49.76	3506.	39245.	52539.	46476.	35393.	2736.	0.742	1.000
4.599	51.88	3569.	38145.	51094.	45198.	34420.	2720.	0.756	1.000
4.649	54.04	3629.	37085.	49700.	43965.	33481.	2705.	0.771	1.000
4.699	56.24	3688.	36062.	48357.	42777.	32576.	2690.	0.785	1.000
4.749	58.47	3745.	35077.	47064.	41633.	31705.	2675.	0.798	1.000
4.799	60.73	3801.	34128.	45818.	40531.	30866.	2661.	0.812	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
4.849	63.03	3855.	33214.	44618.	39469.	30058.	2647.	0.825	1.000
4.899	65.36	3908.	32334.	43463.	38448.	29280.	2634.	0.838	1.000
4.949	67.72	3959.	31486.	42351.	37464.	28530.	2621.	0.851	1.000
4.999	70.11	4009.	30668.	41278.	36514.	27807.	2608.	0.863	1.000
5.049	72.53	4058.	29856.	40213.	35573.	27090.	2595.	0.874	1.000
5.099	74.98	4105.	29061.	39171.	34650.	26388.	2583.	0.885	1.000
5.149	77.46	4152.	28268.	38130.	33730.	25687.	2570.	0.894	1.000
5.199	79.96	4196.	27481.	37098.	32817.	24991.	2556.	0.902	1.000
5.249	82.49	4240.	26710.	36086.	31922.	24310.	2543.	0.910	1.000
5.299	85.05	4282.	25959.	35101.	31050.	23646.	2530.	0.916	1.000
5.349	87.63	4324.	25228.	34142.	30202.	23000.	2516.	0.922	1.000
5.399	90.24	4364.	24519.	33213.	29380.	22374.	2503.	0.928	1.000
5.449	92.87	4403.	23833.	32312.	28584.	21768.	2490.	0.933	1.000
5.499	95.52	4440.	23168.	31441.	27813.	21180.	2477.	0.938	1.000
5.549	98.20	4477.	22525.	30598.	27067.	20613.	2465.	0.942	1.000
5.599	100.89	4513.	21904.	29784.	26347.	20064.	2452.	0.946	1.000
5.649	103.61	4548.	21304.	28998.	25651.	19535.	2439.	0.950	1.000
5.699	106.35	4582.	20724.	28238.	24980.	19023.	2427.	0.953	1.000
5.749	109.11	4615.	20165.	27505.	24331.	18529.	2415.	0.956	1.000
5.799	111.89	4647.	19624.	26797.	23705.	18052.	2403.	0.959	1.000
5.849	114.68	4678.	19103.	26114.	23101.	17592.	2391.	0.962	1.000
5.899	117.50	4708.	18599.	25455.	22517.	17148.	2379.	0.965	1.000
5.949	120.33	4738.	18113.	24818.	21955.	16719.	2368.	0.967	1.000
5.999	123.19	4766.	17644.	24204.	21411.	16305.	2356.	0.969	1.000
6.049	126.05	4794.	17191.	23611.	20887.	15906.	2345.	0.971	1.000
6.099	128.94	4822.	16753.	23039.	20380.	15520.	2334.	0.973	1.000
6.149	131.84	4848.	16330.	22486.	19891.	15148.	2323.	0.975	1.000
6.199	134.76	4874.	15922.	21952.	19419.	14788.	2312.	0.976	1.000
6.249	137.69	4900.	15528.	21436.	18963.	14441.	2301.	0.978	1.000
6.299	140.64	4924.	15148.	20939.	18523.	14106.	2291.	0.979	1.000
6.349	143.60	4948.	14780.	20459.	18098.	13782.	2280.	0.980	1.000
6.399	146.57	4972.	14426.	19996.	17688.	13470.	2270.	0.982	1.000
6.449	149.56	4995.	14083.	19548.	17292.	13169.	2260.	0.983	1.000
6.499	152.57	5017.	13752.	19116.	16910.	12877.	2250.	0.984	1.000
6.549	155.58	5039.	13432.	18698.	16540.	12596.	2240.	0.985	1.000
6.599	158.61	5061.	13123.	18294.	16183.	12324.	2230.	0.986	1.000
6.649	161.66	5082.	12823.	17903.	15837.	12060.	2221.	0.987	1.000
6.699	164.71	5102.	12534.	17525.	15503.	11806.	2211.	0.988	1.000
6.749	167.78	5122.	12253.	17159.	15179.	11559.	2202.	0.989	1.000
6.799	170.86	5141.	11982.	16805.	14866.	11321.	2193.	0.989	1.000
6.849	173.95	5160.	11719.	16462.	14562.	11090.	2184.	0.990	1.000
6.899	177.05	5179.	11464.	16130.	14269.	10866.	2175.	0.991	1.000
6.949	180.16	5197.	11217.	15808.	13984.	10649.	2166.	0.992	1.000
6.999	183.29	5215.	10978.	15496.	13708.	10439.	2158.	0.992	1.000
7.049	186.42	5233.	10746.	15194.	13440.	10235.	2149.	0.993	1.000
7.060	187.11	5236.	10696.	15129.	13383.	10192.	2147.	0.993	1.000

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	3.729	7.060
TRAVEL (IN):	21.21	187.11
VELOCITY (FT/S)	2218.	5236.
ACCELERATION (G):	56351.	10696.
BREECH PRESS (PSI):	75000.	15129.
MEAN PRESS (PSI):	66345.	13383.
BASE PRESS (PSI):	50525.	10192.
MEAN TEMP (K):	3023.	2147.
Z CHARGE 1 (-):	0.460	0.993
Z CHARGE 2 (-):	0.863	1.000

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	323663104.	100.00
(1) INTERNAL GAS:	204413888.	63.16
(2) WORK AND LOSSES:	119249216.	36.84
(A) PROJECTILE KINETIC:	79963376.	24.71
(B) GAS KINETIC:	25038928.	7.74
(C) PROJECTILE ROTATIONAL:	40262.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	391050.	0.12
(F) WORK DONE AGAINST AIR:	1140127.	0.35
(G) HEAT CONVECTED TO BORE:	12675466.	3.92
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	0.730
CHARGE WT/PROJECTILE WT:	1.023
PIEZOMETRIC EFFICIENCY:	0.325
EXPANSION RATIO:	6.403

```
PARAMETRIC VARIABLES: / 1/  OUT   1  PMAX
                      / 2/  PROP  2  CHWT
                      / 3/  PROP  2  DIAM
                      / 4/  PROP  2  PD
                      / 5/  PROP  2  WEB
                      / 6/  OUT   1  VMUZ
                      / 7/  OUT   1  ZMUZ(2)
                      / 8/  OUT   1  LDEN
```

/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/
75000.	6.0000	0.22731	0.20000E-01	0.41828E-01	5236.5	1.0000	0.72978
75000.	6.5000	0.24653	0.20000E-01	0.46632E-01	5320.0	1.0000	0.75258
75000.	7.0000	0.26551	0.20000E-01	0.51377E-01	5396.4	1.0000	0.77538
75000.	7.5000	0.28584	0.20000E-01	0.56461E-01	545[illegible]	1.0000	0.79818
75000.	8.0000	0.30781	0.20000E-01	0.61953E-01	550[illegible]	1.0000	0.82099

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VII. ACKNOWLEDGEMENTS

As stated in the introduction, the intention of this report is to instruct and clarify how to use the IBHVG2 computer code. Although we have worked to improve the computer code in regards to portability and efficiency, Franz Lynn deserves the credit for the creation of IBHVG2. The widespread use of the computer algorithm is a testament to his skill and abilities. His death represents a loss to the interior ballistics community. To be sure, he was sorely missed during the documentation phase of IBHVG2.

We gave considerable thought about including Franz's name on this report. Much of the writing about the input decks and the algorithm comes from his original notes. We decided against it to avoid confusing the readers. Any errors or omissions are solely our own. We are certain that a report with Franz's participation would have been better since he was obviously more knowledgeable about what the code could and could not do.

To thank all the people who helped in writing this documentation or in developing the code would be rather pointless, since it would entail most of the professional staff of Interior Ballistic Division at BRL. However, a few names stand out in particular. A special thanks goes to Fred Robbins for serving as our sublime authority about how to use the code, and to Bob Deas and Paul Baer for motivation about the what and why parts. Stumping these three with a question usually meant some extensive computer experimentation was required. Fortunately, this was an infrequent occurrence.

As a final comment, it is worth mentioning that much of the progress in computer simulations can be directly attributed to experimental developments. From a mathematical standpoint, the equations solved by IBHVG2 are neither original nor particularly complicated. What is new is the data being used to drive these simulations. In-bore measurements, accurate burning rate correlations, and instrumented projectiles have reduced the number of unknowns so that modelers can focus their energies on design and optimization. In this vein, we would like to thank the respective staffs under the direction of Arpad Juhasz for closed bomb firings and Jim Evans for range operations at Sandy Point (Range 18).

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